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FINAL REPORT, PROJECT HERMES V-2 MISSILE PROGRAM

A Report of
Guided Missiles Department
Aeronautic and Ordnance Systems Divisions
Defense Products Group
Schenectady, New York

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Title

FINAL REPORT, PROJECT HERMES V-2 MISSILE PROGRAM

Abstract

THIS IS THE FINAL REPORT ON V-2 OPERATIONS CONDUCTED AT THE WHITE SANDS PROVING GROUND AS PART OF PROJECT HERMES. PRIMARY ATTENTION IS GIVEN TO THE PERFORMANCE OF THE MISSILE AND THE COMPONENTS. OPERATIONAL AND TEST PROCEDURES AS USED AT WSPG ARE DISCUSSED. THE PROGRAM WAS CONCLUDED IN JUNE 1951 AFTER 67 ROCKETS USING V-2 COMPONENTS HAD BEEN CONSTRUCTED, TESTED, AND LAUNCHED.

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Conclusions

THE PROGRAM PROVIDED: (1) BALLISTICS DATA, (2) VEHICLES FOR UPPER ATMOSPHERE RESEARCH PROJECTS, (3) VEHICLES FOR EXPERIMENTS DIRECTLY CONCERNED WITH THE DESIGN OF FUTURE MISSILES, (4) VEHICLES FOR OPERATIONAL TESTS OF FUTURE MISSILE COMPONENTS, AND (5) EXPERIENCE IN THE HANDLING AND FIRING OF LARGE MISSILES.

Information Prepared for PROJECT HERMES, U. S. ARMY ORDNANCE

Tests Made by SERVICE ENGINEERING DIVISION

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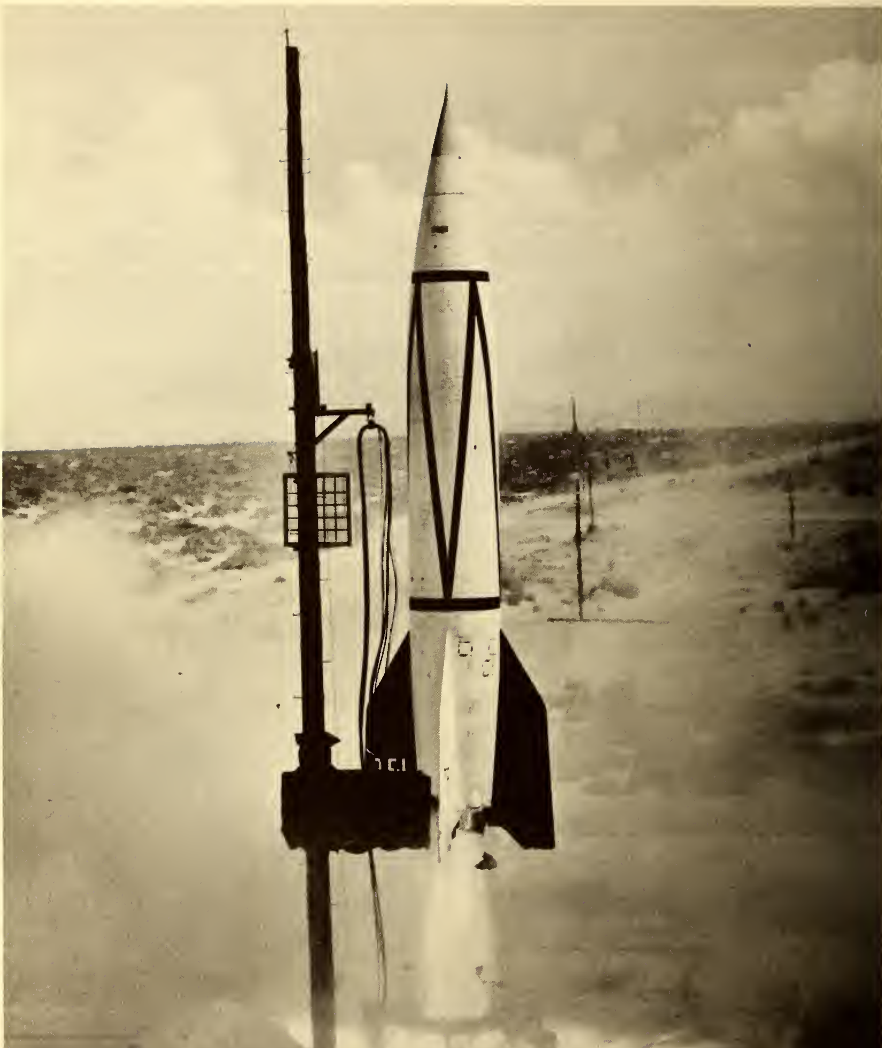

FOREWORD

This report is offered as a final account of V-2 (A-4) operations performed by the Service Engineering Divisions of the General Electric Company at the White Sands Proving Ground under the Hermes Project. It is intended to provide information and experience, concerning the V-2 program, which is not known to be recorded elsewhere. Information which is readily available in other publications has, in general, been omitted from this report. Appropriate references are included.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT'D)

PICTURE CREDITS

The illustrations noted below are published courtesy of U.S. Army Ordnance, White Sands Proving Ground: Figures 4, 6, 7, 8, 9, 11, 22 through 26, 29 left, 31, 32, 34, 35, 38, 43, 44, 45, 47, 48, 49, 51, 52, 57, 58, 59, 68 and 69.

LIST OF TABLES

OBJECTIVES

1. To obtain experience in the handling and firing of large missiles:

   The V-2 missiles offered opportunities not only for the training of military personnel but also for obtaining experience which would be of value in the design of ground equipments for future missiles.

2. To provide vehicles for experiments directly concerned with the design of future missiles:

3. To provide vehicles for operational tests of components for future missiles:

4. To obtain ballistics data:

   The V-2 missiles offered opportunities not only for obtaining ballistics data for high-altitude trajectories but also for developing and proving various means for tracking and measuring these trajectories.

5. To provide vehicles for upper atmosphere research projects:

   At the time this program was initiated the V-2 was the only rocket in existence capable of carrying heavy payloads to a high altitude. This high-load capacity offered agencies the advantage of being able to conduct many related high-altitude experiments simultaneously. Since the V-2 provided many cubic feet of space for experimental apparatus, it was not necessary for the experimental agencies to expend the time and effort necessary to reduce the size of their apparatus to meet the dimensions of smaller missiles.

GENERAL SUMMARY

A large quantity of equipment and components for the German V-2 (A-4) missile was captured in the European Theatre of Operations in 1945. Many trainloads of this material were shipped to Las Cruces, New Mexico, for use at the White Sands Proving Ground (WSPG).

The General Electric Company was assigned the task (as an addition to the existing Hermes Project) of firing a number of V-2 rockets which were to be constructed from the captured components. The work was defined more specifically as follows:

> "In general, this work will consist of the firing of a number of German rockets ..... Also included is the necessary work in connection with the actual firing such as transporting, handling, unpacking, classifying (identifying), reconditioning and testing of components of German rockets as well as assembling and testing subassemblies ahd complete rockets, manufacture of new parts, modification of existing parts, conducting special tests, constructing temporary test equipment not available at the Proving Ground, procuring and handling of propellants and supervision of the launching of rockets."

The captured materiel was unloaded at Las Cruces in August, 1945; with the assistance of military personnel and German specialists, the first rocket was static fired on March 15, 1946 (Fig. 1 and 2). The first rocket was launched on April 16, 1946 (Fig. 3).

By June 30, 1951, the General Electric Company had supervised the construction, test and launching of 67 rockets using V-2 components. General Electric Company participation in the V-2 program was terminated by agreement on June 30, 1951.

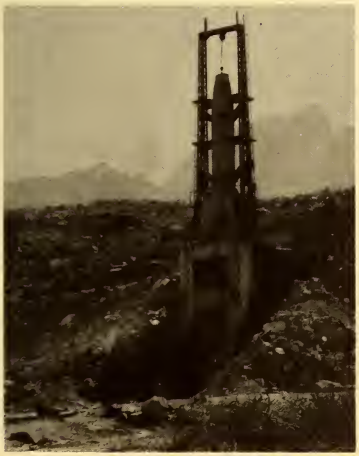

Fig. 1 V-2 Mounted for First Static Test at WSPG

Fig. 2 First V-2 Static Test in Progress at WSPG

Fig. 3 A V-2 Rocket Shortly After Launching at WSPG

PERFORMANCE SUMMARY

1.1 GENERAL STATISTICS

During the program a total of 67 V-2 missiles were launched (Table I). In three of these missiles, the steering system was modified to meet the requirements of the experimental agency. All three showed steering trouble during flight. Since these modifications placed the missiles themselves in the experimental category, they are not included in the performance data that follow.

Fifty percent of the remaining 64 missiles performed normally. In arriving at this percent, any missile which showed any malfunction was counted as a failure, regardless of the adequacy of the trajectory or of the success of the experiments carried. Actually a number of missiles, thus classified as failures because of some known malfunction, were useful from an experimental standpoint. For example, missile 30 failed to steer properly but reached an altitude of 99 miles. Experimental results were reported as excellent. The average altitude of ten of the missiles classified as failures was 80 miles.

To meet the needs of the experimental agencies, 71 percent of all missiles launched were above design weight. The empty weight of the standard V-2 was 8800 pounds which included 2200 pounds of payload (warhead). The average empty weight of all missiles launched was 9218 pounds. This represented an increase of 19 percent in terms of payload. As the program advanced the experimental agencies progressively took advantage of the "work-horse" ability of the V-2 as shown below (these figures do not include the Bumper missiles).

YEAR	POUNDS OF ADDED WEIGHT (ABOVE 8800 LB)	PERCENT ADDED PAYLOAD
1946	150	6.8
1947	400	18.2
1948	527	23.8
1949	1036	47.0

To accommodate experimental needs, there were major contour modifications on 24 missiles. Thus, 36 percent of all missiles launched departed from the design contour in some major respect. There were minor modifications around the nose tip on 11 other missiles. The major modifications became more prevalent as the program advanced.

YEAR	PERCENTAGE OF MISSILES WITH MAJOR CONTOUR MODIFICATIONS
1946	0
1947	7
1948	41
1949	75
1950	80
1951	100

TABLE I, V-2 LAUNCHINGS

(1) Rocket Number	(2) Agency	(3) Date	(4) Time	(5) Empty Weight	(6) Burning Time	(7) Velocity	(8) Altitude	(9) Range	(10) East-West	(11) Program Angle Desired	Obtained	(12) Cut-off by	Remarks
1	WSPG	3-15-46	---	----	57.0	----	---	---	----	---	---	Desk	Static Stand
2	WSPG	4-16-46	2:47 PM	8530	19.0	----	5	0	5.0 E	10.3	---	Radio	Steering bad from lift
3	WSPG	5-10-46	---	8190	59.0	----	70	31.0	2.5 W	10.3	---	Integ.	
4	G.E.	5-29-46	2:12 PM	8696	60.2/63.1	----	70	37.6	----	10.3	9.9	Integ.	
5	G.E.	6-13-46	4:40 PM	9286	58.5/61.2	4220	73	40.0	1.5 W	10.3	9.3	Integ.	
6	N.R.L.	6-28-46	12:25 PM	9807	66.8	4075	67	41.0	0.5 E	10.3	11.4	Burn Out	
7	G.E.	7-9-46	12:25 PM	8977	60.6	4680	83	61.0	1.0 E	10.3	12.4	Time Sw.	
8	G.E.	7-19-46	12:11 PM	9167	28.5	1310	3	0.5	0	10.3	---	Explosion	Explosion at 28.5 seconds
9	A.P.L.	7-30-46	12:36 PM	8562	68.6	5130	104	68.0	9.2 E	10.3	11.8	Burn Out	
10	PRIN.	8-15-46	11:00 AM	9012	18.5	662	2	0.7	0	5.0	---	Radio	Steering Trouble at 13.9 seconds
11	MICH.	8-22-46	10:15 AM	9152	6.5	319	---	0.1	0.4 E	5.0	---	Radio	Steering Trouble from lift
12	N.R.L.	10-10-46	11:02 AM	9164	67.7	5350	102	12.0	10.5 E	5.0	2.0	Burn Out	High Winds at 280°
13	A.P.L.	10-24-46	12:15 PM	9070	59.8	3990	65	17.0	2.5 W	5.0	4.7	Burn Out	
14	PRIN.	11-7-46	1:31 PM	8684	31.0	----	0	5.0s	0	5.0	---	Radio	Steering Trouble at 2 seconds
15	MICH.	11-21-46	9:55 AM	8885	62.5	3876	63	12.6	1.2 E	5.0	3.5	Burn Out	
16	N.R.L.	12-5-46	1:08 PM	9050	69.0	5204	104	---	----	5.0	21.0	Burn Out	Steering Trouble from lift
17	A.P.L.	12-17-46	10:12 PM	8797	69.6	5402	116	21.0	4.0 W	5.0	3.0	Burn Out	
18	N.R.L.	1-10-47	2:13 PM	9434	60.0	4400	72	25.0	5.0 W	7.0	6.0	Burn Out	Roll at 40 seconds
19	G.E.	1-23-47	5:22 PM	9140	59.0	2300	31	10.3	12.0 W	7.0	---	Burn Out	Not Standard Steering System
20	A.M.C.	2-20-47	11:16 AM	9390	58.0	4062	68	13.9	11.0 W	7.0	---	Burn Out	Steering Disturbance at 27 sec. Roll at 37.3
21	N.R.L.	3-7-47	11:23 AM	9182	63.0	5120	100	35.0	2.2 E	7.0	---	Burn Out	
22	A.P.L.	4-1-47	1:10 PM	8800	57.0/60.5	4457	80	24.0	3.0 E	7.0	5.6	Time Sw.	Wind 50 mph at 290°
23	A.P.L.	4-8-47	5:10 PM	8840	57.0/60.0	3825	64	19.0	0.7 W	7.0	5.2	Time Sw.	
24	G.E.	4-17-47	4:22 PM	9061	66.0	4710	87	45.0	6.5 W	7.0	8.5	Burn Out	Roll at 57.5 seconds
26	N.R.L.	5-15-47	4:08 PM	9827	63.5	4696	76	35.0	31.0 E	7.0	9.6	Burn Out	Steering Trouble from lift
29	N.R.L.	7-10-47	12:18 PM	9522	32.0	1450	10	1.4	1.0 E	7.0	---	Radio	Steering Trouble from lift
30	A.P.L.	7-29-47	5:55 AM	8533	62.5	4962	99	1.0s	3.2 W	7.0	---	Burn Out	Vane #4 ceased to operate at 27 sec
27	G.E.	10-9-47	12:15 PM	9107	62.5	4987	97	28.0	16.5 W	7.0	---	Time Sw.	Steering Disturbance at 48.4 sec. Roll at 52
Special	G.E.	11-20-47	4:47 PM	9249	39.0	1632	13	1.5	1.0 E	7.0	---	Fault	Propulsion Trouble at 36 sec
28	A.M.C.	12-8-47	2:42 PM	9493	61.5	3939	65	28.0	1.0 E	7.0	7.2	Burn Out	
34	N.R.L.	1-22-48	1:12 PM	9548	67.0	4985	99	48.0	1.0 E	7.0	7.0	Burn Out	
36	G.E.	2-6-48	10:17 AM	8789	65.8	4300	70	1.4s	3.7 E	7.0	---	Burn Out	Not Standard Steering System
39	G.E.	3-19-48	4:10 PM	9659	25.0	720	3	1.0s	0.5 E	7.0	---	------	H_2O_2 Exhausted
25	S.C.	4-2-48	6:47 AM	9742	69.5	4682	89	48.0	2.0 W	7.0	9.1	Burn Out	
38	N.R.L.	4-19-48	12:54 PM	9169	57.0	3679	35	32.0	7.0 W	7.0	---	Radio	Steering Trouble from 13 sec or earlier
BU-1	G.E.	5-13-48	6:43 AM	8573	64.5/67.9	4010	70	32.0	2.0 W	7.0	8.3	Integ.	
35	A.P.L.	5-27-48	7:15 AM	10411	62.4/65.5	4600	87	41.0	2.0 W	7.0	7.7	Time Sw.	
37	A.M.C.	6-11-48	3:22 AM	10161	57.3	3013	39	17.0	1.0 W	7.0	---	Fault	Premature Valve Closure
40	A.P.L.	7-26-48	11:03 AM	9942	60.8	3770	60	23.0	1.5 E	7.0	7.1	Burn Out	Pulsation Starting at 45.2 sec

(1) Rocket Number	(2) Agency	(3) Date	(4) Time	(5) Empty Weight	(6) Burning Time	(7) Velocity	(8) Altitude	(9) Range	(10) East-West	(11) Program Angle Desired	Obtained	(12) Cut-off by	Remarks
43	N.R.L.	8-5-48	5:07 AM	8993	65.5	5200	104	53.0	7.0 W	7.0	8.6	Burn Out	
BU-2	G.E.	8-19-48	7:45 AM	8082	33.8	1250	8	0.9	0.4 E	7.0	---	Fault	Premature Valve Closure
33	S.C.	9-2-48	6:00 PM	8422	63.0/65.4	4822	94	40.0	2.5 W	7.0	6.7	Time Sw.	
BU-3	G.E.	9-30-48	8:30 AM	8052	56.5/70.2	4625	93	22.0	2.0 W	4.3	4.3	Radio	
BU-4	G.E.	11-1-48	7:24 AM	8105	28.5	1280	3	1.0s	1.5 E	4.3	---	Exp.	Tail Explosion at 28.5 sec
44	G.E.	11-18-48	3:35 PM	8858	65.5	4760	90	29.0	6.0 E	7.0	5.1	Burn Out	High winds
42	S.C.	12-9-48	9:08 AM	8234	60.6/64.0	4030	67	25.0	12.0 E	7.0	8.5	Time Sw.	Vane 2 to Zero at 22 sec
45	N.R.L.	1-28-49	10:20 AM	9537	56.5	2925	37	10.5	4.0 E	7.0	5.1	Radio	High winds - Low Thrust
48	A.P.L.	2-17-49	10:00 AM	9652	63.5	4440	79	37.0	1.0 E	7.0	8.2	Burn Out	
BU-5	G.E.	2-24-49	3:14 PM	8732	61.0/64.5	3800	63	21.5	6.0 E	2.5	6.7	Integ.	
41	A.M.C.	3-21-49	11:43 PM	9971	65.5	4460	80	32.4	0.8 E	7.0	6.8	Burn Out	
50	S.C.	4-11-49	3:05 PM	9530	62.5	3450	53	20.0	0.3 E	7.0	6.4	Time Sw.	Pulsation Starting at 43.4 sec
BU-6	G.E.	4-21-49	5:17 PM	8651	48.0	2660	31	0.4	1.2 W	2.5	---	Fault	Premature Cut-off at 47.5 sec
46	G.E.	5-5-49	8:15 AM	9200	25.6	1050	5	1.4	0.9 E	7.0	---	Fault	Premature Cut-off at 25.7 sec
47	A.M.C.	6-14-49	3:35 PM	10575	67.3	4407	83	37.0	2.0 W	7.0	7.0	Burn Out	
32	A.M.C.	9-16-49	4:19 PM	9996	24.7	783	3	0.5	0.7 W	7.0	---	Exp.	Tail Explosion at 10.7 sec
49	N.R.L.	9-29-49	9:58 AM	9276	65.5	4960	94	43.5	3.0 W	7.0	8.1	Burn Out	
56	S.C.	11-18-49	9:03 AM	10414	66.4	4250	77	32.0	2.0 W	7.0	8.0	Time Sw.	
31	A.M.C.	12-8-49	12:15 PM	10211	65.0	4430	79	37.8	1.5 W	7.0	8.4	Burn Out	
53	N.R.L.	2-17-50	11:00 AM	9900	65.0	4825	92	40.5	1.8 W	7.0	6.7	Burn Out	
BU-8	G.E.	7-24-50	9:29 AM	8575	----	----	---	----	----	---	---	Integ.	Excessive Program
BU-7	G.E.	7-29-50	6:25 AM	8665	----	----	---	----	----	---	---	Integ.	Excessive Program
51	A.M.C.	8-31-50	10:09 AM	10683	64.9	4600	85	36.1	1.9 W	7.0	7.5	Burn Out	
61	B.R.L.	10-26-50	4:02 PM	8807	49.7	3153	---	----	----	---	---	Exp.	O.K. to 50 sec Special Program
54	N.R.L.	1-18-51	1:14 PM	9296	44.0	300	1	0.5	0.1 W	7.0	---	Burn Out	Lox Flow Low
57	A.M.C.	3-8-51	8:16 PM	10407	18.5	642	2	0.2s	0.6 E	7.0	---	Exp.	Tail Explosion at 15.5 sec
55	N.R.L.	6-14-51	6:48 AM	9192	0	0	0	0	0	7.0	---	Exp.	Separation Explosives Detonated
52	A.M.C.	6-28-51	2:43 PM	9781	22.0	825	4	0.4	0.6 E	7.0	---	Radio	Tail Explosion at 8.0 sec

Explanation of columns:

(2) WSPG, White Sands Proving Ground; GE, General Electric Company; NRL, Naval Research Laboratory; APL, Applied Physics Laboratory of John Hopkins University; PRIN, Princeton University; MICH, University of Michigan; AMC, Air Materiel Command; SC, Signal Corps; BRL, Ballistic Research Laboratory, Aberdeen Proving Ground.

(3) month/day/year; (4) Mountain Time Zone except BU-7 and 8 which are Eastern Time Zone; (5) pounds; (6) seconds; (7) feet per second; (8), (9) and (10) miles; (11) degrees.

1.2 RESULTS OF PROPULSION-UNIT CALIBRATION

In late 1947 the calibration of propulsion units (Fig. 4) was started at WSPG. The data given below offer some idea of the improvement in performance which resulted. It should be noted that the data does not include any correction for differences in take-off weight, trajectory or missile configuration. The lack of such correction should not introduce any serious errors in the averages.

Comparison has been limited to missiles which: (1) burned to propellant exhaustion and (2) gave no evidence of malfunction. Records were available on 19 missiles which satisfy these conditions. The following data are based on eight missiles which were not calibrated at WSPG and on 11 missiles which were calibrated at WSPG.

	ALTITUDE Miles	EMPTY WEIGHT Pounds
Calibration by German test records	89.1	9064
Calibration by WSPG test	88.5	9764

It is noteworthy that the units calibrated at WSPG were able to carry an average of 700 pounds additional load while the average altitude remained essentially constant.

The WSPG calibration also produced much more consistent results. In terms of altitude the deviation from average was +18 and -11 percent (79 to 104 miles). Using German test records, the deviation from average was +30 and -29 percent (63 to 116 miles). For many experiments this improvement was of considerable value.

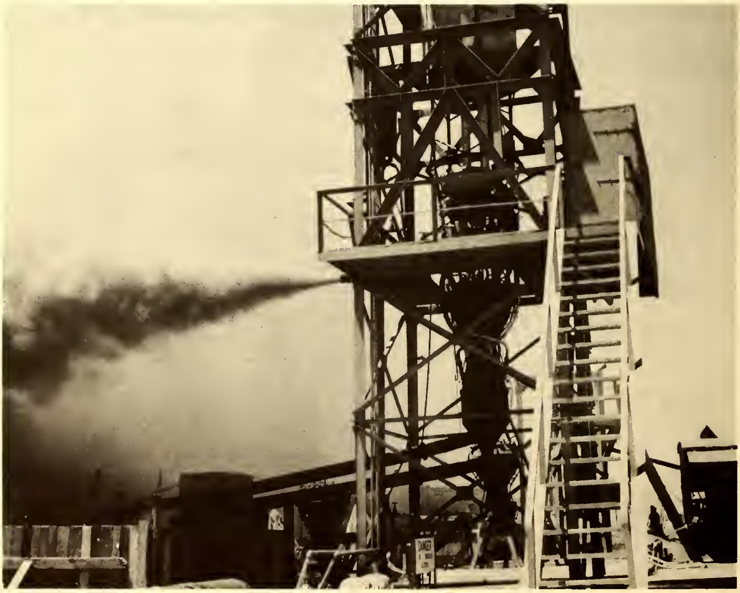

Fig. 4 Propulsion Unit Calibration in Progress

1.3 FAILURES

1.3.1 Definition

In arriving at general performance figures the missiles are divided into two classes, "Normal" and "Failures." A missile was classified as a failure if there was any known malfunction or if the missile performance indicated the probability of a malfunction. This classification is based on performance as a missile and not as an experimental vehicle. As previously noted, a number of missiles, here classed as failures, produced very useful flights from an experimental viewpoint.

1.3.2 Investigation

Based on the above definition, 32 missiles were classed as failures. In each case, a thorough investigation was conducted in an attempt to identify the cause of failure. In general, the results of these investigations were disappointing. In most cases it was possible to determine the general nature of the fault but the exact origin was seldom located with certainty. A detailed report of each failure is included in Appendix D, section 2, this report.

There were three primary sources of information concerning faults in flight: telemetry, recovery, and optics. Both recovery and optics contributed very valuable information on occasion, but these occasions were somewhat rare. Telemetry provided a large percentage of the total information.

Normally, six telemetry channels were assigned to missile performance. Although four of these channels were usually sub-commutated to monitor twelve functions, only a small fraction of all the possible sources of trouble could be covered. On no occasion were the channel assignments and timing ideal for giving a complete picture of the malfunction.

1.3.3 General Distribution of Malfunctions

In view of the limited information available, it was seldom possible to identify the exact component which failed. However, the data which follow should present a fair picture of the types of failure encountered.

Over the entire program the missile failures were divided almost equally between steering and propulsion (steering 14, propulsion 15, and miscellaneous 3). It should be noted, however, that this division was not typical of all phases of the program. After the twenty-seventh launching, most of the German-made components of the steering system were replaced by components of domestic manufacture. The main exception was the servo, which was completely overhauled and equipped with a US-made motor. In addition, all German cables were replaced with new cables made of stranded wire. These changes resulted in a pronounced improvement in steering performance. Prior to these changes, 46 percent of the missiles showed steering trouble. After the changes only five percent showed this trouble.

1.3.4 Time of Failure

A review of time-of-failure data offers some indication of the factors which caused the failures. For example, if a missile was in trouble from the instant of lift, there is a strong presumption that the initiating conditions were present, or at least set up, prior to lift. The factors which would allow such conditions would include stray potentials, inadequate test and personnel errors. On the other hand, if a missile performed normally for a number of seconds of flight, there is a strong presumption that any subsequent failure was produced by in-flight conditions. It seems probable that vibration accounted for a high percentage of in-flight failures.

In most cases the time of failure has been established with reasonable accuracy. It was not always possible, however, to detect a steering fault in the first few seconds of flight. The following data are based on the assumption that any steering fault detected within the first five seconds was present at lift.

	NUMBER	PERCENTAGE OF TOTAL
FAULTS AT LIFT		
Steering	6	19
Propulsion	3	9
Miscellaneous	3	9
TOTAL	12	37
FAULTS IN FLIGHT		
Steering	8	25
Propulsion	12	38
TOTAL	20	63

As shown in the table below, the in-flight failures were rather uniformly distributed throughout the powered flight. There is a slight suggestion of concentration in the speed-of-sound zone (20 to 30 seconds) but these few samples are not sufficient to establish this point.

TIME OF FAULT Seconds	TYPE OF FAULT
8.0	Propulsion
10.7	Propulsion
13.0	Propulsion
13.9	Steering
15.5	Propulsion
22.0	Steering
24.3	Steering
25.7	Propulsion
27.0	Propulsion
28.2	Propulsion
28.5	Propulsion
33.0	Propulsion
36.6	Propulsion
38.0	Steering
43.4	Propulsion
45.2	Propulsion
47.5	Propulsion
48.4	Steering
56.4	Steering
57.5	Propulsion

1.3.5 Allocation of Faults

As stated previously, the precise origin of failure often remained in doubt. Therefore, any allocation of faults is subject to question. The following list is an estimate based on available information.

SOURCE OF FAULT	AT LIFT	IN FLIGHT
Components	4	7
Wiring	0	7
Piping	1	5
Stray potentials	2	0
Personnel errors	3	0
Unidentified	1	2

1.3.6 Effect of Low Temperature Due to Liquid Oxygen

It was general practice to minimize the time during which lox was present in the missile, but many factors introduced unavoidable delays. The time from start of lox loading (Fig. 5) to take-off varied from 80 to 536 minutes. There has been considerable interest in the relation of this time to the probability of a successful flight.

Reliable time figures are available for 40 missiles. These data indicate that there was no appreciable change in percentage of successful flights for the period from 80 to 120 minutes. Beyond the two hour wait-time, there was a marked drop (65 to 39 percent) in the percentage of successful flights.

The value of these figures is limited since: (1) forty samples are not enough to establish any definite data and (2) all failures were counted, although it is highly improbable that they were all due to low-temperature effects. In view of the limitations, no definite probability curve is justified. It would appear, however, that a wait-time time in excess of two hours should be avoided whenever possible.

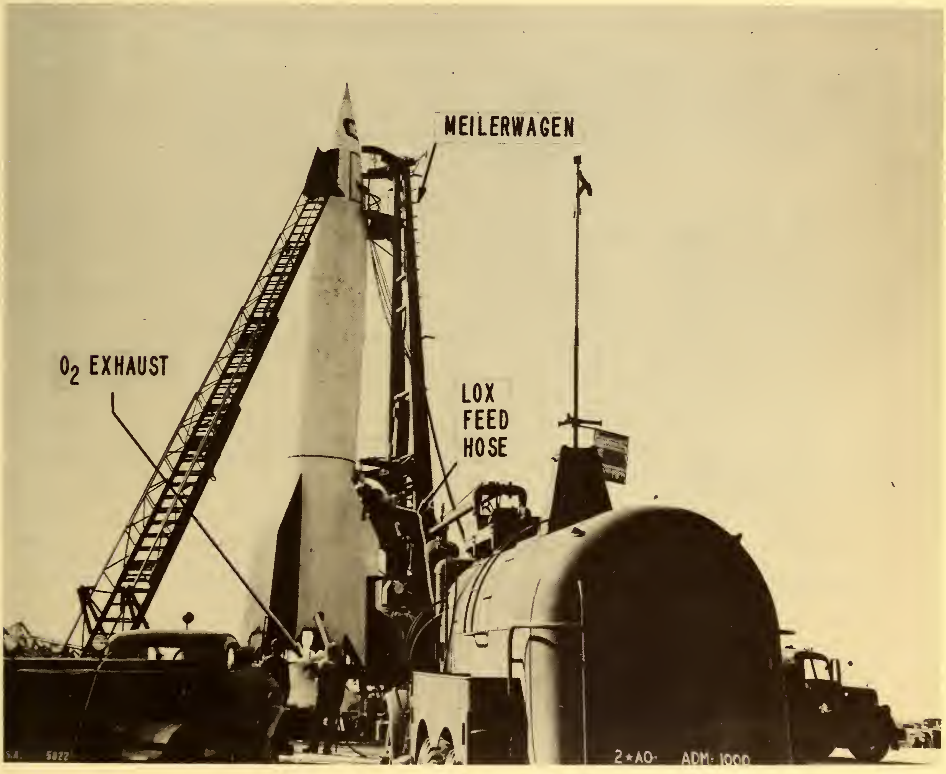

Fig. 5 V-2 Being Loaded with Oxygen

MISSILE COMPONENTS

The following is a brief summary of each major V-2 component covering quantities received, condition, performance and other general comments.

Detailed descriptions of the components may be found in reports by Project Hermes[1] and the British Special Projectiles Operation Group[2]. Information on the use of these components at WSPG is noted in the Appendix of this report.

WARHEAD

Quantity	:	Approximately 50
Condition	:	Good, no repairs required
Performance	:	Good
Comments		Very few of the German warheads were used. For the housing of experimental equipment the German units were unnecessarily heavy and offered very poor access. Many of the experimental warheads were made by the Naval Gun Factory and supplied to the program by the Naval Research Laboratory. There were also a number of special warheads constructed for special applications.

CONTROL CHAMBER (section containing missile control equipment)

Quantity	:	Approximately 115
Condition	:	Varied from good to very poor, considerable repair required
Performance	:	No known cases of failure

MIDSECTION

Quantity	:	Approximately 127 sets
Condition	:	Good to poor, moderate repairs required
Performance	:	No known failures

THRUST FRAME

Quantity	:	Approximately 100
Condition	:	Generally good, few repairs required
Performance	:	No known failures

TAIL SECTION

Quantity	:	Approximately 90 in usable condition
Condition	:	Good to poor, considerable repair required on many
Performance	:	No known failures
Comments		Toward the end of the program it was necessary to have eight units built in the U. S. A.

PROPELLANT TANKS

Quantity	:	Approximately 180 for each reactant
Condition	:	Generally good, some welding repairs required. Leaks were usually found at support attachments requiring additional rivets.
Performance	:	No known failures
Comments	:	Workmanship, particularly welding, was excellent, practically no deterioration noted after approximately seven years.

TURBINE AND PUMPS

Quantity	:	Approximately 200
Condition	:	Generally excellent, only minor repairs were made.
Performance	:	Good, one known failure where bearing seized.
Comments	:	Oxygen seals (three, steel, 120-degree segments with garter springs) required considerable attention; cleaning and lapping were required. Turbine blades were exceptionally sensitive to steam temperature; much cleaning was required after calibration runs.

BURNER

Quantity	:	Approximately 215
Condition	:	Varied from good to unusable. Included were obsolete types, unfinished and untested burners and rejects.
Performance	:	Good, no known case in which burner failed. Most burners were recovered and inspected carefully. Evidence of one small defect which did not ruin flight was found. There was possibility, unsupported by evidence, that small cracks in head might have contributed to one or more tail explosions.
Comments	:	Although burners were stored in the open for years, there was remarkably little evidence of deterioration. Considerable effort was required, however, to remove scale and accumulated dirt from interior of burners. Calibration tests (Fig. 6) were adequate to establish proper mixing ratio and flow rate. No known method, other than static firing, was considered adequate for checking the effects of pressure, temperature and vibration.

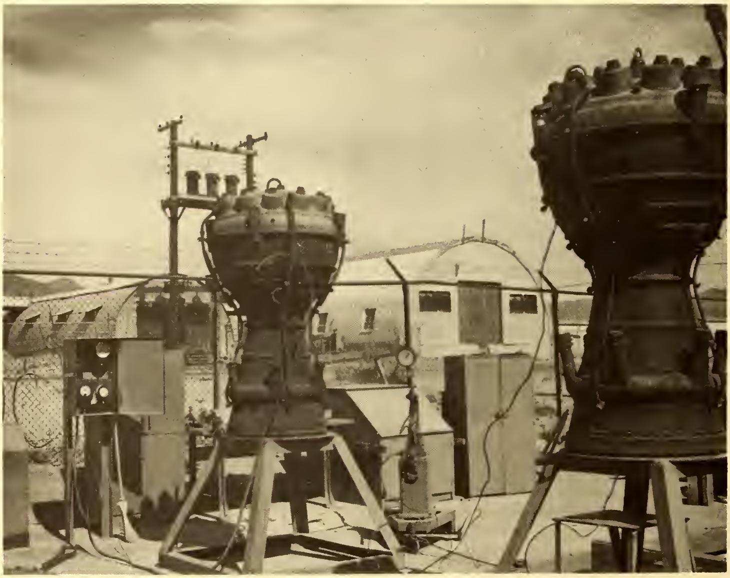

Fig. 6 V-2 Burners in Test-Preparation Area

HYDROGEN PEROXIDE TANK

Quantity	:	Approximately 200
Condition	:	Excellent, with quantities available, no repairs were required.
Performance	:	Excellent, no known failures.
Comments	:	These tanks were made of steel which was not compatable with hydrogen peroxide. To prevent decomposition, the tanks were lined with a special protective coating. The Germans suspected that age would cause this coating to crack and become useless. One coated tank was used for 13 calibration runs. After these runs it was beginning to show signs of "distress" but was not considered to have reached the danger point.

PERMANGANATE TANK

Quantity	:	Approximately 200
Condition	:	Excellent, with quantities available, no repairs were made.
Performance	:	No trouble experienced

HEAT EXCHANGER

Quantity	:	Approximately 100
Condition	:	Good to poor, some required considerable repair.
Performance	:	No trouble experienced

AIR BOTTLES

Quantity	:	Approximately 115 sets
Condition	:	Bottles were generally good mechanically but rusted inside. Manifolds frequently were in poor condition; some manifolds were constructed.
Performance	:	No trouble experienced
Comments	:	Rust was cleaned from inside the bottles by rotating while partially filled with abrasive fragments. Bottles,that were pressure-tested to destruction, showed a remarkably consistent failure both as to pressure and type of rupture. The fail-point was approximately twice the working pressure.

STEAM GENERATOR

Quantity	:	Approximately 200
Condition	:	Excellent, very little repair required.
Performance	:	No known trouble

VALVES (GENERAL)

In general, there were enough valves of each type available (lox vent and alcohol drain excepted) to allow valves with serious defects to be discarded without attempting major repairs. As described in Appendix A, many of the valves required minor repairs. In addition, there was some concern about the effects of age on the rubber seals used in some valves. It seemed certain that deterioration of the rubber would eventually render those valve useless. With this in mind, a program was arranged to develop, test and install new seals in a limited number of valves.

OXYGEN VALVE

Quantity	:	Approximately 200
Condition	:	Varied from good to unusable. After the best valves had been used, considerable effort was required to provide acceptable valves.
Performance	:	Generally satisfactory, but there were a few instances in which these valves were suspected of having contributed to propulsion failures.
Comments	:	It was definitely established that there was excessive leakage past the rubber seal of this valve. A new seal was developed. In addition, a metal-to-metal seal also showed excess leakage. Various corrective methods were tried but none were particularly successful. Additional details are noted in Appendix A.

ALCOHOL MAIN VALVE

Quantity	:	Approximately 200
Condition	:	Varied from fair to poor, many rejected.
Performance	:	No known trouble during flight.
Comments	:	The most common defects were porous cases and rough stroke; for details see Appendix A.

ALCOHOL PRELIMINARY VALVE

Quantity	:	Approximately 190
Condition	:	Generally good, although many required minor repairs.
Performance	:	No known failures in flight. On one or two occasions the valve was suspected of closing prematurely, but this was more likely to be a failure of the controls than of the valve itself.

OXYGEN VENT VALVE

Quantity	:	Approximately 80, it was necessary to manufacture additional units in US.
Condition	:	Generally fair, adjustments and minor repairs were required.
Performance	:	No known failures in flight.
Comments	:	Details are rated in Appendix A.

GYROSCOPES

Quantity	:	Approximately 50, (two required per missile)
Condition	:	Varied from poor to unusable; many of the usable gyros required extensive reconditioning.
Performance	:	Generally good; although steering troubles were frequent during the time these gyros were in use, the trouble was seldom attributed to the gyros.
Comments	:	The German gyro, in good condition, gave excellent performance. From a design viewpoint it had two weaknesses of secondary importance. The torque-motor spiders were of a material which distorted and produced binding when hot and the program motor was slightly weak. For details, see Appendix C.1. It was necessary to procure 140 additional gyros of domestic manufacture. These were essentially copies of the German gyro with minor improvements and changes to US standards. In performance they were fully equal to those of German origin.

MIX-COMPUTER (AUTO-PILOT SERVO AMPLIFIER)

Quantity	:	Approximately 70
Condition	:	Varied from fair to unusable; useful units required test, adjustment and replacement of defective components.
Performance	:	Poor, there were five flights in which the computer was suspected of causing steering trouble.
Comments	:	The computer failures were not attributed to poor design but rather to deterioration of components. The tubes in particular had a high "mortality rate" under vibration tests. It was necessary to procure 80 computers of domestic manufacture. These were essentially a copy of the German design using US-made components. The only design change of any importance reduced the maximum voltage within the computer. The performance of the US computers in flight was excellent. For details see Appendix C.2.

TIME SWITCHES

Quantity	:	Approximately 350 (two types)
Condition	:	Good, corroded solder joints were the principal defects.
Performance	:	Excellent; no known trouble in flight.

SERVOS

Quantity	:	Approximately 500
Condition	:	Varied from fair to unusable. After the best servos had been used, it was necessary to install new motors and completely overhaul the remaining units.
Performance	:	Apparently good, while there were seven flights in which the observed steering trouble could have been caused by a servo failure, there was, in each case, some other type of failure which seemed more probable.
Comments	:	For further comment on servos, see Appendix C.3.

INVERTERS

Quantity	:	Approximately 600 (two or more required per missile).
Condition	:	Good; with quantity available, little repair was required.
Performance	:	Good, no known failures in flight. It was occasionally necessary to replace an inverter at the launching site, but much of this trouble was attributed to dust and sand.

REGULATORS (FOR INVERTERS)

Quantity	:	Approximately 600 (one required per inverter).
Condition	:	Good, very little repair necessary.
Performance	:	Excellent
Comments	:	An excellent design, held inverter frequency very close over a wide range of input voltage and a wider range of load. The unit had no moving parts and occupied little space.

MAIN DISTRIBUTORS (MISSILE RELAY AND JUNCTION BOX)

Quantity	:	Approximately 70
Condition	:	Varied from good to unusable. Some units were unwired. All units required modification.
Performance	:	Generally good, no known failures, although several of the flight malfunctions could have originated in the distributors.
Comments	:	The majority of the German relays were of good design and workmanship and showed little response to vibration. The wiring showed good workmanship but was subject to breakage because of the use of small, single-strand wire. Electrical connectors were fair. It was necessary to manufacture approximately 30 distributors. These were essentially copies of the German design, although it was necessary to substitute some relays of US manufacture. The most important change was the use of stranded, instead of single-strand, wire.

ELECTRICAL CABLES

Quantity	:	An adequate supply for 100 missiles
Condition	:	Fair, connectors and workmanship were good but small, single-strand wire was used.
Performance	:	Questionable, it is probable that some of the early missile failures were caused by wire breakage.
Comments	:	The use of the single-strand wire appeared so questionable that all main German cables were scrapped in 1947. Stranded wire was used in new cables.

JET VANES

Quantity	:	An adequate supply for 100 missiles (three types received)
Condition	:	Varied from good to unusable; many vanes were rejected in test.
Performance	:	Good, there were only two flights in which there was any suspicion of vane failure.
Comments	:	Good performance could be expected from properly tested and protected vanes but the percentage of rejected vanes was high. Detailed information on the jet vanes is presented in Appendix A.

TEST, REPAIR AND ASSEMBLY

3.1 GENERAL

There appears to have been a fairly widespread impression that many missiles were received virtually complete and ready for flight. This was completely erroneous. No missiles were received in anything resembling a flyable condition. If complete missiles had been received, the first step would have been to disassemble them so that the individual components and subassemblies might be tested properly (German experience proved that there was a large increase in in-flight failures when assembled missiles were stored for an extended period). All missiles launched under this program were assembled (Fig. 7) at WSPG from basic components.

All basic components were individually tested and inspected for performance and condition prior to assembly (detailed test instructions will be found in the Appendix). Repairs and adjustments were made as required, after which, tests were repeated. All basic components met established test specifications before being assembled in larger subassemblies or in the missile itself.

Larger subassemblies received complete tests before being assembled in the missile. One of the most elaborate of these tests was the calibration (Fig. 4, p. 8) of the propulsion unit. This test is summarized under a separate heading and is presented in detail in Appendix B.

The completely assembled missile was given two over-all tests before leaving the Missile Assembly Building (Fig. 8). At the launching site, one over-all test was completed prior to launching day. The same test was repeated on launching day immediately before the loading of propellants. It was an established rule that no connections could be broken after final test.

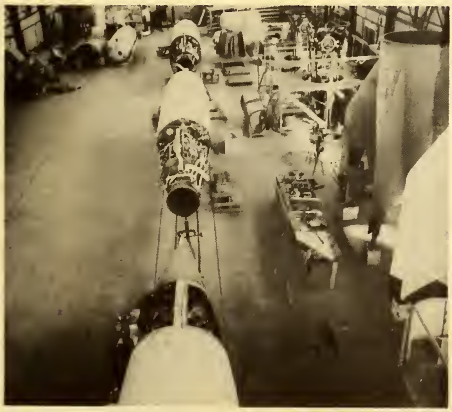

Fig. 7 Missile Assembly Building at WSPG with Three V-2's Nearing Completion

Fig. 8 Missile Assembly Building at WSPG V-2 in Foreground is Being Tested

3.2 PROPULSION UNIT CALIBRATION

Propellant ratio and flow rate are influenced by three major components: the steam plant (Fig. 9), the turbine-pump unit and the burner (Fig. 10). In Germany these components were tested separately. From the test records it was possible to select the proper orifices with acceptable accuracy.

Test records were available at WSPG for a limited number of components but the results obtained by this method were far from consistent. Two missiles, fired within a 30-day period, and having empty weights within one-percent of the nominal design value, gave altitudes of 63 and 116 miles. This was probably the result of changes in the components, particularly the burner, after the tests in Germany.

It was apparent that local tests would be required if consistent results were to be obtained. With the assistance of German specialists, a calibration stand (Fig. 11) was designed and constructed. This equipment was arranged to calibrate the entire propulsion system as a unit, contrasted to the German method of separate tests on individual components.

As experience was gained, a number of modifications and improvements were made (Appendix B). The final arrangement was considered to give very acceptable results. Flight performance and static burning tests indicated that there was little to be gained by further refinements.

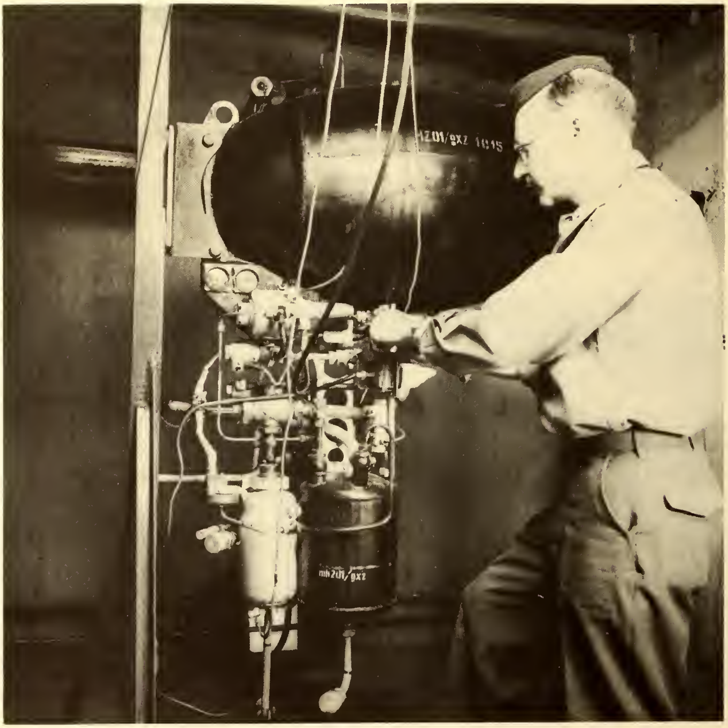

Fig. 9 V-2 Steam Plant Being Tested Prior to Assembly in Rocket

Fig. 10 Burners Being Prepared for Test

Fig. 11 Propulsion Unit Calibration Stand

3.3 STRUCTURE

The primary structural components, exclusive of the warhead, are listed below. A description of each of these components will be found in the "Backfire," report[3] Vol. 2, on the pages indicated. The weights given are for the bare structural elements before the installation of any other equipment.

COMPONENT	"BACKFIRE" REFERENCES	WEIGHT Pounds
Control chamber	page 9, par 10 page 94, Fig. 56	385
Midsection (Two, half shells)	page 10, par 11 page 93, Fig. 46 and 47	985
Thrust frame	page 90, Fig. 39	155
Tail unit	page 14, par 13 page 14, Fig. 4 and 5	1110

In general, it was not necessary to make major repairs to critical members of the various structural components. The wooden parts of many of the control chambers were in poor condition but the steel framework, and particularly the important longitudinal members, were in relatively good condition. It was necessary to construct new plywood crosses for about 75 percent of the control chambers. Since these crosses provided an appreciable percentage of the strength of the chamber, care was taken to see that the new crosses were fully as strong as the original German units.

The midsection shells (Fig. 12) were generally in fair condition. In many cases the skin was torn, and patching was frequently required, but the ribs and longitudinal members seldom showed serious damage. Since there was a surplus of about 25 percent from which to select, major repairs were not required.

In the case of thrust frames, there were barely enough to complete the program. Fortunately, the ones available were generally in good condition. The alignment of this frame was a matter of some importance and the construction of new frames or the extensive repairs of old ones would have called for the manufacture of a fairly elaborate fixture.

A few extra tail units (Fig. 13) were received but several, out of the total, were damaged beyond repair. Some obviously had been damaged in Germany prior to being crated, certain units were damaged by handling and a few were damaged by wind and weather.

A high percentage of the damage consisted of injury to the fins (mostly the buckling of structural members and misalignment of the fins). This type of damage could not be repaired properly without a large and fairly accurate fixture to position the fins with respect to the body of the tail (any appreciable misalignment would result in excessive demands on the steering system). In addition, special welding apparatus would have been required, as well as facilities for the construction of the fins themselves. Consideration of the various factors lead to the conclusion that it would not be feasible to set up the necessary facilities at WSPG. Consequently, an order was placed with the Douglas Aircraft Company, Inc. for the construction of eight new tail units. These consisted of the basic structure only. All the related accessories and equipments were provided and installed by the Hermes Project.

All tail units, old and new, were tested at WSPG for fin alignment to avoid the use of any tail which might overload the steering system. Since the fins of the old tail units had been positioned by fixture in Germany, it was assumed that they were still located, with sufficient accuracy, at 90 degrees to each other. Consequently, no elaborate check was made in this respect. The test at WSPG was primarily concerned with the detection of any misalignment which might have occurred after the original assembly.

This test was made by means of a Wild theodolite which was capable of measuring angles to one second. The theodolite was set up on a line through a pair of opposite fins, such as 1 and 3, at a distance of 20 feet from the outer bottom edge of the fin to be examined. Selected reference points on the tail unit were used to establish the long axis of the tail. The tail was then shifted until this axis was vertical and the "zero-point" of the fin fell in a plane through the tail axis and the theodolite. Zero-point of the fin was defined as the point at which the top of the fin merges with the body of the tail. With these conditions established, the deviation of points along the edge of the fin can be measured in terms of angle. Readings can be converted to linear terms if desired. This process was repeated for each fin.

Fig. 12 Control Cables Being Laid in V-2 Midsection

Fig. 13 V-2 Tailsections at WSPG

A survey work-sheet for the alignment test is shown in Figure 14. Point A on this sheet is the point previously defined as the "zero-point" of the fin. Point B was located at the center of the knee of the fin. Point C was the extreme outer and bottom (aft) point of the fin. Intermediate readings were taken when the need was indicated. From the work sheet it will be noted that the maximum allowable deviation for any given fin was ±6.75 mm at Point B. The total allowable deviation at this point for all four fins (with due consideration to direction) was 9.75 mm. At Point C the maximum allowable deviation for any given fin was ±15.0 mm. Total allowable deviation at Point C for all four fins was 20.0 mm.

C. Surveying of Tail Fins

Fin I	**Point A**	**Point B**	**Point C**
Difference between point		A - B	A - C
Distance of Transit		ft. =	mm
Difference in mm = $\frac{\text{Distance of Transit in mm}}{57.3 \times 3600} \times$ Angle in sec			
Fin III	**Point A**	**Point B**	**Point C**
Difference between point		A - B	A - C
Distance of Transit		ft. =	mm
Difference. in mm = $\frac{\text{Distance of Transit in mm}}{57.3 \times 3600} \times$ Angle in sec			
Fin II	**Point A**	**Point B**	**Point C**
Difference between point		A - B	A - C
Distance of Transit		ft. =	mm
Difference in mm = $\frac{\text{Distance of Transit in mm}}{57.3 \times 3600} \times$ Angle in sec			
Fin IV	**Point A**	**Point B**	**Point C**
Difference between point		A - B	A - C
Distance of Transit		ft. =	mm
Difference in mm = $\frac{\text{Distance of Transit in mm}}{57.3 \times 3600} \times$ Angle in sec			
Allowed difference in mm for each fin		± 6.75	± 15.0
Allowed Total Diff. for all four fins		± 9.75	± 20.0
Measured Total difference in mm			

Tested by:______________________ Date: ______________________

Fig. 14. Tail Unit Fin-alignment Work Sheet

Although about 50 of the standard German warheads were received, very few were used in this program. There were two objections to the use of German warheads for the housing of experimental equipment: (1) they were heavier (550 pounds) than required for the purpose and (2) they offered very poor access to equipment mounted inside. Many of the experimental warheads were made by the Naval Gun Factory and supplied to the program by the Naval Research Laboratory. In addition, there were a number of special warheads constructed for special applications.

A series of modified V-2 Missiles, known as Blossom were launched with the Air Force, Cambridge Research Laboratories, as the cognizant agency. In addition to the warhead of special construction, these missiles were further distinguished by an increase in length of one caliber (approximately 65 inches). Standard German midsection shells were delivered to the Air Force and the structural modifications were carried out under the direction of the Franklin Institute Laboratories for Research and Development. The development, design and construction concerned with this modification are thoroughly covered by a two-volume report, F-2106, issued by the Franklin Institute Laboratories for Research and Development.

Seven missiles were included in this particular Blossom series. All were heavily loaded. The lightest had an empty weight of 9781 pounds (normal empty weight of the standard V-2 was 8800 pounds). The heaviest had an empty weight of 10,683 pounds and the average was 10,232 pounds. Of the seven missiles, four resulted in successful flights. The velocities and altitudes attained were about normal for the weights involved. There was no evidence that the change in structure had any appreciable effect on the trajectory. It is of interest to note, however, that all three failures were of the same type: tail explosions early in the flight (missile No. 32 at 10.7 seconds, No. 57 at 15.5 seconds and No. 52 at 8.0 seconds).

The forward portion of the V-2 structure was modified for a series of two-stage missiles known as Bumper (Fig. 15). Over-all responsibility for these missiles was given to the General Electric Company and included in the Hermes Project. The Jet Propulsion Laboratory of the California Institute of Technology was assigned responsibility for the theoretical investigations required, the design of the second stage and basic design of the separation system. The Douglas Aircraft Company was assigned responsibility for fabircation of the second stage and detail design and fabrication of the special V-2 parts required. A general report on the Bumper vehicle is given in General Electric Company – Project Hermes report R50A0501. Structural aspects are covered in Douglas Aircraft Company Reports 12266 and SM-13178. The latter contains references to related reports by the Jet Propulsion Laboratory.

A total of eight Bumper Missiles were launched. As far as V-2 performance was concerned, three were successful, three failed and two were partially successful. In the case of the latter two, the program was somewhat influenced by a "sneak" circuit, but this was in no way connected with the structural changes. The three failures conceivably could have been caused by excessive vibration due to the changes, but there is little evidence to support this possibility. Two of the faults were of a type previously experienced on missiles of more conventional construction. The third failure, a tail explosion at 28.5 seconds is of more interest. The only other known tail explosions occurred in the Blossom series of missiles, which, like Bumper, involved major structural changes.

Two missiles were prepared for launching at sea under Operation Sandy. The only structural modification consisted of a moderate reinforcement of the fins. Since the fins carry the full weight of the loaded missile, it was considered desirable to add strength at this point to provide for any added load which might be introduced by the ship's motion. Two triangular plates of 1/8-inch steel were attached to the bottom of each fin, one plate on each side of the fin. The outboard edge of the plate was attached to the main vertical member of the fin by self-tapping screws. The upper edge was attached to the bottom horizontal member of the fin; the remaining edge was attached to the diagonal member extending from the bottom of the fin to the base of the fin near the edge of the burner. A strap of 1/8-inch steel, about two inches in width, was welded to the plate and extended along the main vertical member up to the bend in the fin. Since the ship had virtually no roll or pitch after the missile was loaded, the effectiveness of the modification was not tested.

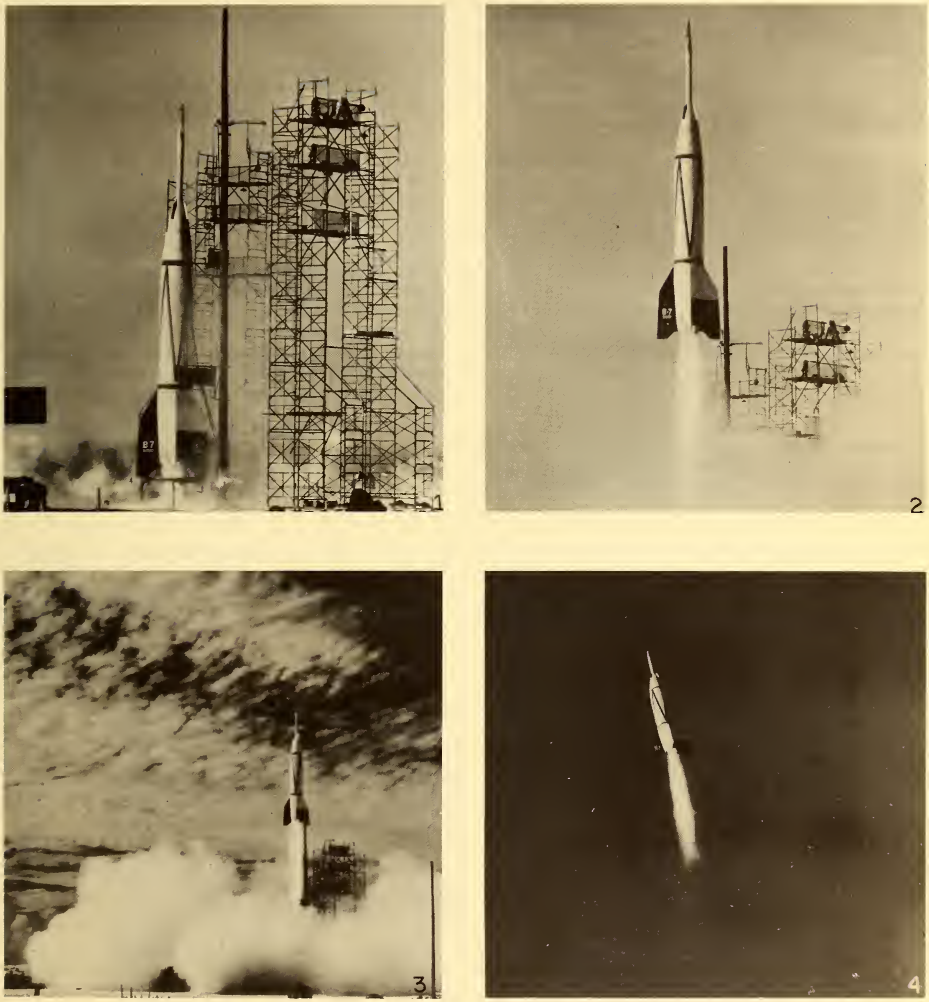

Fig. 15 Bumper Missile Launching Sequence

The two missiles for Operation Sandy were shipped from WSPG to Norfolk, Virginia by rail. Special arrangements, regarding the careful handling of the shipment, were made in advance and a detail of military personnel rode with the missiles. It appeared, however, that the shipment received rough treatment. When the missiles arrived at Norfolk, it was found that both tail sections had been damaged. In each case, the body of the tail had buckled a few inches aft of the forward end of the tail on the side which was down during shipment. It is believed that the damage was primarily due to the type of support used at the base of the burner and aggravated by the rough handling.

Bumper missiles 7 and 8 were shipped to Florida by military truck. The shipping cradle was exactly the same type as used on Operation Sandy, with one exception: the rigid tail support located at the base of the burner was replaced by a partially-inflated truck tire. The Army vehicles were driven with care and both missiles arrived in Florida in excellent condition. This trip provided a clear demonstration that large missiles of this type can be transported for long distances without damage, structural or otherwise.

German test records on new V-2 missiles indicated that the structure could withstand lateral accelerations in the order of 3g. The structural components used at WSPG were far from new and had been subjected to weather and much handling. On this basis, some structural failures might have been expected. However, on the favorable side was the fact that a much smaller program was normally used at WSPG. The typical German program was 47 degrees, while that at WSPG was usually 10.3 degrees or less. In any event there is only one known case, in this program, of a missile having been lost because of a structural failure. In that one case, the failure is believed to have resulted from excessive heat due to a very unusual trajectory.

Although the usual program was 10.3 degrees or less, there were three flights for which the program was 70 degrees or more. In each case the standard German midsection, thrust frame and tail unit were used. No attempt was made to provide extra strength at any point. All three missiles made this relatively hard turn (70 degrees or more) successfully and without any evidence of trouble, structural or otherwise.

GROUND EQUIPMENT

4.1 GENERAL

The captured equipment included an adequate but limited amount of essential mechanical ground equipment. Among the major items were Meilerwagens, launching platforms, lox trailers, hydrogen peroxide trailers, alcohol pump trailers, and compressor trailers. In general these items were in poor condition and required considerable reconditioning before using.

The situation with respect to electrical ground equipment was poor. Virtually every item required was built at WSPG with the help of German specialists. In a way, this was fortunate since it presented an opportunity to learn the equipment in detail.

4.2 MECHANICAL EQUIPMENTS

4.2.1 Meilerwagen[4]

The primary functions of this device (Fig. 16) were to erect the missile on the launching platform and to provide working platforms after erection. The erecting force was provided by a hydraulic system, including telescoping pistons.

In general, this device was well designed for field use, but it had two objectionable features. First, the hydraulic system required excessive maintenance, partially due to the exposed pistons. Second, it did not always position the missile properly on the launching stand. In an attempt to insure proper positioning, the Meilerwagen was coupled to the platform prior to erection. If the coupling was tight enough to position the missile accurately, it was difficult to mesh with the Meilerwagen. If it was loose enough for easy meshing, the position of the missile might be unsatisfactory. Thus, either extreme, or any compromise in between, was likely to result in excessive erection time.

Fig. 16 Left to Right, Meilerwagen used for Transporting and for Erecting the V-2. Figure 20 shows this Unit in the Vertical Position.

4.2.2 Launching Platform[5]

This device was essentially an adjustable table mounted over a flame deflector. It provided facilities for leveling and rotating the erected missile. The platform was simple and gave no trouble, however, two features were added. Detachable plates were provided to prevent the missile from "walking" off the table by action of wind gusts. In addition, provisions were made for discharging carbon dioxide into the burner by remote control, in case of emergency.

4.2.3 Liquid Oxygen Trailer[6]

This trailer was used by the Germans to transport lox from railroad tank cars to the launching site. Since lox was delivered direct to the missile (Fig. 5, p.11) by the supplier, the trailers were not required for their original purpose at WSPG. Instead, they were used for the mixing and transport of alcohol. These trailers had one outstanding weakness, the outlet at the bottom of the tank was so constructed that it could not withstand severe road shock.

4.2.4 Hydrogen Peroxide Trailer[7]

This trailer (Fig. 17) had provisions for warming the peroxide and for pumping it to a measuring tank on the Meilerwagen. The peroxide was surrounded by a water jacket; water was heated by a gasoline heater. Pumping was by a hand pump which was a constant source of trouble.

Since the heater was not required at WSPG and since the pump was poor, the use of the trailer was discontinued. Peroxide was ordered in exact quantities so that two drums made one charge. These drums were hoisted to a platform about ten feet above the missile peroxide tank and the peroxide loaded by gravity feed.

Fig. 17 German Hydrogen-Peroxide Trailer Used to Load V-2 Missile at WSPG

4.2.5 Alcohol Pump Trailer[8]

This trailer (used to load alcohol into the missile) contained a gas-engine driven pump, a filter and metering equipment. After a short time the gas engine was replaced by an electric motor. The meter was checked periodically and found to be accurate and reliable.

4.2.6 Compressor Trailer[9]

The Germans used this trailer to compress gas to about 3500 psi for use in the missile. It contained its own silica gel dryers which were reactivated by heat from the exhaust of the compressor engine. It also contained a rack of storage bottles.

When V-2 operations were started at WSPG, there were no other 3500 psi compressors available. With the help of German specialists, these compressors were reconditioned and placed in service. They were fairly simple to operate and performed moderately well considering their condition. Since practically no spare parts were available, it was something of a problem to keep them in operating condition. Further, there was not too much confidence in the reliability of their safety devices. When domestic compressors became available, use of the German compressors was discontinued.

From later experience it was learned that the German dryers were not fully effective. Some regulator troubles at the launching site were attributed to inadequately-dried air. A dew point indicator showed that further drying was desirable. A series of tests indicated that the dew point could be brought down to about -100°F by silica gel, but to do so required considerable more baking of the gel than was previously thought necessary.

4.3 ELECTRICAL EQUIPMENTS

4.3.1 Firing Desk

Among the principal electrical items were the firing desk (Fig. 18) and its associated relay box (Fig. 19). These were built at WSPG using German materials for the most part. The desk and relay box were built separately and connected by plug-in cables. This was suggested by the German arrangement in which such division was desirable for portability.

Connections between the desk and the relay box were a source of considerable trouble. The contacts in the German "Flak" plugs were good but there was insufficient space in the plugs for fanning out from the cable to the contacts. In addition, the wires in the German cables were insulated with a thin cotton cover which very readily became loose exposing the wire. The result was many shorts and grounds. Later, a new desk was constructed with the relay panel built into the desk. This eliminated the interconnecting cables and a major source of trouble. The new equipment contained a much larger percentage of US-made devices.

The German firing equipment was designed with the intent of placing minimum requirements on the operator. Many security circuits were included to interrupt the firing sequence automatically in the event of improper conditions. The desk was provided with a number of indicating lights to show the source of such a hold. These provisions added to the complexity of the ground equipment. Approximately 120 wires were required for control and monitoring of the missile; some 60 relays were used in the ground control equipment.

4.3.2 Cast-off Cables

To keep missile weight at a minimum, the ground control wires were connected to the top of the missile by external cables (Fig. 20) which were cast off just prior to lift. The cables terminated at the lower end in Flak plugs of the type previously described. At the missile end a "Stotz" plug was used. A special cable, having exceptional flexibility, aided in the process of casting the plugs free.

The Stotz plug had adequate space for fanning the cables to the contacts, and the contacts themselves were excellent. An appreciable amount of trouble was experienced with these plugs, but it should be noted that they were subjected to very severe duty. The release mechanism was simple and effective. The only unfavorable feature was the fact that its gear sector showed excessive wear.

Fig. 18 V-2 Firing Desk Built at WSPG

Fig. 19 Rear View of Firing-Desk Relay Box

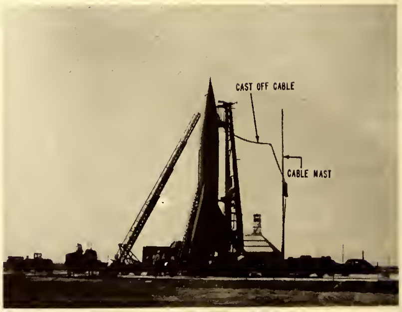

Fig. 20 V-2 Being Erected for Launching

EQUIPMENT AND PROCEDURE MODIFICATIONS

Since the primary purpose of the V-2 program was to provide an experimental vehicle, not a tactical missile, no attempt was made to carry on development leading to changes in the standard German components.

The capabilities of the standard system and of the standard components had been established, with fair accuracy, through some thousands of launchings in Germany. It was felt that the factors of time, economy and reliability were opposed to any major departures from these standards.

When the program was extended to cover one hundred rockets, it became necessary to procure certain components of domestic manufacture. These components included the gyros, computer, main distributer, oxygen vent valve, tail structure and most of the piping (Fig. 21). In general, these components retained all the basic features of the originals. Only minor changes were made to utilize domestic materials, methods and standards. The one exception to this was the computer, and even in that case the change was not of a fundamental nature. However, during the program experience brought out certain beneficial changes which could be made without sacrifice of reliability.

5.1 CALIBRATION OF PROPULSION SYSTEM AS A UNIT

The procedure in Germany consisted of testing the steam plant, the turbo-pumps and the motor as separate units. From the data thus obtained, orifices were selected by calculation. At WSPG the turbo-pump, the motor and the associated piping were calibration-tested as a unit after being assembled (Fig. 21) for flight (Appendix B.2).

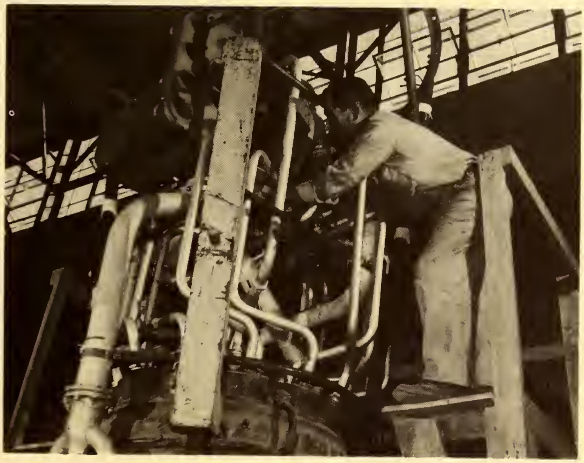

Fig. 21 Propulsion Unit Assembly Nearly Completed at WSPG

5.2 OMISSION OF ALCOHOL TANK PRESSURIZATION ON RE-ENTRY

In tactical use, the alcohol tank was pressurized after burning ended to prevent collapse on re-entry into the lower atmosphere. This required three air bottles, plus associated valves and piping. Since air break-up was desired on most WSPG flights, this equipment was omitted, thus providing additional space for experimental equipment and reducing the dead weight by about 65 pounds.

5.3 SECONDARY SOURCE OF AIR PRESSURE FOR VENT VALVE

The oxygen tank vent valve was held open by air pressure from a ground supply. If the ground supply should fail with oxygen in the tank, the relief valve was the only safety measure remaining. For safety of personnel and protection of equipment, provisions were made to allow a quick switch to a separate, secondary source of pressure.

5.4 LOADING OF OXYGEN AFTER HYDROGEN PEROXIDE

In tactical operations, oxygen loading was started before hydrogen peroxide loading. This was a reasonable procedure since oxygen loading required only about 12 minutes and provisions were available for topping, if required, up to the time of lift.

At WSPG, oxygen loading required 35 minutes and topping-to-lift facilities were not available. Although these conditions were somewhat less favorable than those for German launchings, the German sequence of loading was used successfully for many launchings at WSPG.

During operations in Florida, condensation of moisture proved to be a source of some difficulty. Under such conditions, there was a definite advantage in loading oxygen as late as possible. The practice of loading oxygen last was used initially in Florida and later continued at WSPG. There were two secondary benefits. First, there was less oxygen evaporation; second, there was less probability of having to remove the oxygen because of delays. The latter was of some importance, since the removal of oxygen would cause condensation of moisture within the oxygen system.

5.5 SUBSTITUTION OF ELECTRIC MOTOR FOR GAS ENGINE DRIVES

The alcohol pump and the hydraulic pump of the Meilerwagen were originally driven by gas engines. These engines were replaced by an electric motor to: (1) reduce the fire and explosion hazard, (2) reduce maintenance and (3) increase reliability.

5.6 SUBSTITUTION OF AUDIBLE LEVEL INDICATOR FOR FLOAT SWITCHES

Two float switches were used originally to give warnings as the level of alcohol reached the overflow point. These switches were not entirely reliable because of the possibility of a sticky float, a loss of signal power or an open circuit. On one occasion, the launching of a rocket was delayed when the failure of a float switch resulted in an overflow of alcohol.

To avoid such occurrences, a warning device was developed which had the advantages of no moving parts, no power supply and no electrical connections. In addition, it gave a continuous indication that the alcohol level was rising.

The device consisted of a two-tone whistle which was accurately positioned in the tank at the time the volume of the tank was measured. Two openings in the whistle intake caused a characteristic tone to be produced by the air which was being expelled by the rising alcohol level. When the alcohol level closed the lower opening, the tone changed abruptly, giving a preliminary warning. When the alcohol level closed the upper opening, the whistle ceased to function. This was the signal to stop pumping.

5.7 ADDITIONAL VENTING OF LOX VALVE CONTROL CHAMBER

During the latter part of 1948 it became evident that the composition seals on certain valves were showing the effects of age.

One seal on the lox valve was particularly troublesome. This seal was intended to prevent leakage between the control chamber and the lox passages of the lox valve. Leakage of liquid oxygen into the control chamber would result in pressure tending to force the lox valve closed. During flight, the control chamber was vented through several feet of small diameter piping but this vent was too small to prevent a pressure build-up in case of heavy lox leakage.

The development of a new seal was started but an interim measure was considered desirable. The bottom plug in the control chamber of the lox valve was tapped to take one of the German 25-ton hydrogen peroxide valves. This valve was pneumatically operated through a pilot valve whose coil was connected in parallel with the coil of the pilot valve for the main alcohol valve. The outlet of the 25-ton valve was piped outside the tail, through 18 inches of 25 mm tubing. Thus, the vent area was increased by about 600 percent while the length was decreased about 50 percent. It is believed that this modification was effective in preventing malfunctions due to the leakage described above.

5.8 HYDROGEN PEROXIDE LOADING BY GRAVITY

In tactical operations in Germany, H_2O_2 was transferred from a bulk container to a loading dolly. From this dolly it was transferred by a hand pump to a measuring tank mounted on the Meilerwagen and then loaded into the rocket tank by gravity feed.

After the above procedure had been used at WSPG for a number of V-2 missiles it became apparent that (with the facilities available) a much better procedure could be devised. This consisted of hoisting the original shipping drums to an upper level of the Gantry crane; from there, the H_2O_2 was gravity-fed into the rocket tank. This method reduced the hazard, maintenance, loading time and cost.

5.9 CHANGE OF MISSILE POWER RELAY

In the original German design, the relay B2y(10), which connected the main power battery to the rocket bus, was de-energized in flight. Vibration tests showed that this relay, when de-energized, was particularly susceptible to vibration. There was a decided improvement in this respect when the relay was energized. Since even the momentary opening of "back" contacts on this relay could ruin the flight, and since there was some cause to suspect that this had happened on one flight, the circuit was changed so that B2y was energized in flight.

As added insurance that B2y would remain energized in flight, its seal-up circuit was paralleled by a switch which was closed at lift. This switch was of a type that was virtually vibration-proof.

5.10 COMMAND-CURRENT CIRCUIT CHANGE

In the original design, the command currents to the servos were routed through milliammeters in the remote steering desk until the Stotz plugs were dropped. To do this, the direct connections from the computer to the servo coils were opened when relay R2x was energized. Since the coil of R2x was energized from the ground, the direct connections from computer to servos were supposedly re-established by "back" contacts of R2x when the Stotz plugs dropped. If any of these failed to make adequate contact, due to dirt, vibration, etc., the rocket would be launched without steering control.

To avoid the possibility of trouble from the fault described above, a change was made in this circuit. Resistors of 6.8 ohms were connected across the contacts of R2x, and the milliammeters in the steering desk were replaced by millivoltmeters. The low value of resistance was selected to insure that there would be negligible effect if it should be left in series with the servo coil. With this arrangement, no trouble would be expected if R2x should fail to close any, or all, or its back contacts.

5.11 CHANGE IN GROUND CUT-OFF RELAY CIRCUIT

After experience had indicated the need, the Germans added an auxiliary relay, A90z, to permit cut-off from the ground after the normal control cables had been disconnected from the rocket. This relay was not included in the main distributor but was mounted separately. As originally installed, the closing of a "make" contact of A90z would energize the cut-off relay, A9z, from the rocket bus. If vibration caused the contact of A90z to close, premature cut-off would result. Although there was never any direct evidence proving this circuit to be at fault, some cut-off trouble was experienced. As a result, the circuit was modified so that A90z received power to energize A9z from a ground source, only. Thus cut-off would not occur in flight if the contacts of A90z should close.

5.12 COMPUTER CHANGES

The US-built computers contained no changes in basic circuits. However, minor changes were made to lower the maximum voltage within the computer thus reducing the possibility of arc-over at high altitude.

5.13 CHANGE IN STEERING TEST

In the original procedure the response of the steering system was tested by tilting the missile through the use of jacks on the launching platform. This method was slow and did not give strong signals. At WSPG the gyro plate was unbolted from the rocket and tilted by hand. This allowed rapid motion of the gyros which produced strong signals that were easily recognized. It should be noted that the cables to the gyros were made long enough to allow this operation without disconnecting any of the final flight wiring.

5.14 ADDITION OF ROLL ERECTION MONITOR FOR PITCH GYRO

In the original design there was no provision for monitoring the roll erection of the pitch gyro. The probability of trouble from this source was believed to be too small to justify any elaborate means of checking. It was found, however, that this function could be monitored in a very simple way. Low-energy coils of two relays, located at the launching desk, were connected in parallel with the erecting coils of the gyro. The contacts of these relays were used to control signal lights. Thus, normal drift-and-erection could be observed at the control desk.

5.15 ADDITION OF ROLL ERECTION MONITOR FOR ROLL-YAW GYRO

It was learned by experience that a short circuit (or an open circuit) could exist at any point between the roll gyro pick-off and the Computer input without being detected at the steering desk. Under this condition a rocket could be launched without roll control.

A very simple method of correcting this situation was used at WSPG. The pick-off voltages had always been brought back to the control desk to energize relay R12p. By connecting a zero-center voltmeter across the coil of R12p, it was possible to watch the normal drift-and-erection sequence. The absence of such action would serve as a warning.

5.16 RELOCATION OF VANE-BALANCE POTENTIOMETERS

In the original design, the vane-balance potentiometers were spaced around the base of the missile, each back of a separate hatch secured by seven screws. An excessive amount of time was required for final vane balance. Since the operation was performed after lox loading, it was desirable to reduce this time to a minimum. To accomplish this, all four potentiometers were moved to one location. The pot shafts were brought out flush for ease of operation; the adjustment openings were closed with clip buttons. These changes reduced the required time by several minutes.

5.17 ADDITION OF ISOLATION SWITCH IN PITCH CONTROL

The standard steering system included a circuit for synchronizing the pitch vanes. No means were provided for making the circuit inoperative during vane balance. The result was that drift in one vane would cause similar motion of the opposite vane. It was not possible to determine readily which vane originated the motion. There was, therefore, an equal chance that the drift would be stopped by introducing a balancing drift in the opposite vane. Under normal conditions this would have no adverse effect on the flight. If, however, the synchronizing circuit should become inoperative during the powered flight, there was a strong probability that the rocket would roll.

To avoid this possibility, a simple isolation switch was installed so that the synchronizing circuit could be opened during vane balance. Thus, each pitch vane was adjusted independently for zero drift. With this method there was a strong probability that roll would not result if the synchronizing circuit became inoperative. It should be noted that the isolation switch was of the spring-return type so that the synchronizing circuit could not be left open by error.

5.18 NEW SERVO MOTORS

The power of the German servo motor was low for the application. When full load was applied, the speed would drop to approximately 50 percent of the no load speed. With a new servo mechanism in excellent condition, the motor was barely adequate. Most of the servos received at WSPG had begun to show the effects of usage. Cylinders, pistons and gear pumps showed wear and the leakage, particularly with hot oil, was appreciable. This, coupled with poor speed regulation, produced a very marginal condition.

An aircraft-type motor of domestic manufacture was modified to replace the original German motor. The current requirement of the new motor was somewhat higher, but the speed regulation was virtually flat from no load to full load. In addition to the new motor, the cylinders, pistons and gear pumps were re-worked to reduce leakage. These modified servo units had more than adequate power.

MISSILE BREAK-UP INSTALLATIONS

Very early in the program, explosives were installed in the missile for the purpose of separating the warhead from the missile body. Both range safety and the recovery of experimental apparatus, required warhead separation. For range safety it was considered desirable to be able to alter the trajectory by destroying the missile contour. Separation was essential to the recovery of experimental equipment. No recovery could be expected from a missile that was not broken prior to impact. Figure 22 shows the crater and recovered parts from missile 34 which landed without separation.

Various methods of separation were tried. In one of the earlier attempts, strands of primacord were secured to the tail skin about one foot aft of the junction with the midsection. Recovery showed that the skin had been cut as desired but the tail had not separated from the rest of the missile. It appeared that cables, piping and other structural elements had held the tail in place.

The most effective means of break-up was found to be the destruction of the four longitudinal members of the control chamber. Initially, two pounds of TNT were used at each member. This proved to be more than required. One pound of TNT per member was found to be adequate and this amount was used for most of the missiles.

On a number of missiles the TNT was placed at the forward end of the control chamber and satisfactory separation usually resulted. Later the TNT was moved to the aft end of the control chamber and even better results were obtained. Explosives at the aft end of the control chamber not only destroyed the longitudinal members but also blew out the forward end of the alcohol tank.

It was found that best results were obtained when the explosives were detonated before the missile reentered the denser atmosphere. There was photographic evidence which showed that the warhead could remain in position to impact when the explosives were detonated after the missile was nose-down in dense atmosphere. Unless experimental requirements dictated otherwise, it became standard practice to effect warhead separation at 40 miles, or higher, on the downward leg of the trajectory.

With proper separation, the impact of the after end of the missile was surprisingly gentle. Figures 23, 24 and 25 show the midsection and tail of a missile which landed from an altitude of 76 miles after a successful separation. Recovery of experimental equipment from such impacts was generally excellent. Figure 26 shows recovery of a Naval Research Laboratory spectrograph which was mounted in the fin of a missile that had reached an altitude of 97 miles. A spectrograph of this type survived two impacts, with only moderate repairs needed. However, the spectrograph was damaged beyond repair on its third impact.

Since the explosives were a possible source of danger to personnel, safety precautions were given careful attention. The details of these procedures are given under "Safety," Section 9.

Fig. 22 Crater After Impact of Missile 34.
Recovered Parts Can Be Seen at Lower Right.

Fig. 23 Midsection and Tail of Missile 26 After Impact

Fig. 24 Tailsection of Missile 26 After Impact

Fig. 26 Spectograph Being Removed From V-2 After Impact

Fig. 25 Midsection of Missile 26 After Impact

V-2 OPERATIONS OUTSIDE WSPG

7.1 OPERATION AT SEA

In 1947 two missiles were assembled at WSPG for launching at sea under Operation Sandy. These missiles were constructed essentially the same as those launched at WSPG, with only minor modifications to meet unusual requirements. The tail structure was reinforced to a moderate extent and certain modifications were made in the steering system.

The missiles were transported to the east coast by rail. Arrangements were made to provide careful handling in transit and a special detail rode with the missiles. Even after these precautions, the missiles apparently suffered considerable damage enroute.

On board ship other agencies provided special equipment for holding the missile and for transferring oxygen. One missile was launched on September 6, 1947. A discussion of the launching appears in Chief of Naval Operations report OpNav P57-110, "Report of Operation Sandy," September 6, 1947.

7.2 OPERATION AT LONG RANGE PROVING GROUND, COCOA, FLORIDA

Two missiles were assembled at WSPG for this operation. Both were of standard Bumper (Fig. 15, p 25) construction except for program modification.

The missiles were transported to Cocoa, Florida, by standard Army tractors and flatbeds. The cradles were essentially the same as those used for Operation Sandy. The main modification of the supporting cradle consisted of a partially inflated truck tire located near the base of the burner. This provided a non-rigid support for the tail. Both missiles arrived at their destination in excellent condition.

In general, the conventional V-2 ground equipment was used. The one major change was in the type of working platform used to service the upper levels of the missiles. The platforms were made up of standard commercial iron pipe scaffolding of the type commonly used by painters. These assemblies were mounted on casters. The scaffolds, extending to about 55 feet above the concrete pad had sufficient strength and rigidity for the purpose. It is felt that this type of service platform should find increasing application in missile work, since it: (1) can be disassembled into small, light sections and transported in regular military vehicles, (2) can be moved into position (or removed) rapidly when assembled, (3) can be used with a variety of missiles since the basic structure can be assembled to suit the needs of the job and (4) is relatively inexpensive.

The first launching attempt was unsuccessful. Collected moisture caused a fuse to blow when the main stage signal was given. This resulted in a complete shut down of the propulsion system. The missile was not damaged, but it was necessary to return it to the hangar to be checked and dried properly.

Two steps were taken to reduce the probability of further condensation troubles: (1) silicone grease was applied at vulnerable points and (2) the loading sequence was reversed to load lox after loading hydrogen peroxide. These measures proved adequate in two subsequent launchings.

The first missile was launched July 24, 1950, and the second July 29, 1950. Results of these launchings are discussed in Patrick Air Force Base – Long Range Proving Ground Division, Technical Report No. 1, "Bumper Missiles 7 and 8," September 29, 1950.

PERSONNEL

8.1 GENERAL

In the early days of the program a tentative goal of 25 missiles was established. It was thought that this work could be accomplished by approximately ten General Electric Company engineers working with German specialists and military personnel.

As the program advanced there were two upward revisions in the total number of rockets to be fired. In addition, it as found that the original schedule of one rocket per week did not allow sufficient time for the reduction and analysis of data. It became evident that the program would continue for a much longer time than originally planned. For these and other reasons it was decided that G-E would arrange for a group of sufficient size to assemble, test and launch missiles, on a one-every-two-weeks schedule, without "outside" assistance. In keeping with this decision, German specialists were gradually replaced by G-E personnel and by the spring of 1947 all German specialists had been replaced.

By the end of 1947 the number of G-E personnel had reached thirty-four. From that time to the end of the program there was no significant change in the number of personnel. The following was the typical division of assignment:

Engineers & Engineering Assistants	17
Shop Personnel, Mechanical	11
Shop Personnel, Electrical	3
Clerical & Administrative	3
Total	34

It should be noted that G-E activities at WSPG were not confined entirely to the assembly, test and launching of the missiles themselves. Almost all of the missiles carried a large amount of experimental apparatus. The General Electric group devoted an appreciable percentage of its time to the modification of the missiles to accommodate this apparatus. Considerable time was also spent in the installation and wiring of this equipment.

Experimental work associated with the missiles required the extensive use of telemetry equipment. From September of 1947 to the spring of 1949, approximately 60 man-months were devoted to telemetry work.

Additional activities included assisting the Navy in the assembly and test of three special V-2 missiles. These missiles were not complete in all respects but did involve (due to special requirements) the expenditure of an appreciable amount of time by G-E personnel.

Two operations were conducted away from WSPG. In one operation, a V-2 was launched at sea from an aircraft carrier (Operation Sandy). On another occasion two missiles were launched from the Long Range Proving Ground in Florida. Each of these operations involved an expenditure of man-hours many times greater than that normally required for the launching of a comparable missile at WSPG. Six G-E engineers from WSPG accompanied the V-2 for Operation Sandy. Eighteen engineers assisted directly in launchings at the Long Range Proving Ground.

Although it was general policy to schedule missiles at two-week intervals, there were never more than 17 missiles fired in any one year. This reduction from a nominal 26 missiles per year did not result from a lack of personnel. The most important factors contributing to the reduction were: (1) experimental requirements and (2) operations away from WSPG. It is believed that a force of 34 would have been adequate to sustain a schedule of 26 V-2 missiles per year.

In a continuing operation of this type the turnover of personnel has an important bearing on the effectiveness of the group. This program was very fortunate in having an exceptionally low turnover.

8.2 SCHENECTADY WORKS PERSONNEL

The preceding comments refer to personnel regularly assigned to WSPG. It should be noted that this by no means covers all G-E people contributing to the V-2 program. The group at WSPG received a large amount of support from various divisions of the Company. The greater part of this support was provided by the Aeronautic and Ordnance Systems Divisions and the Service Engineering Divisions in Schenectady. Within these units there were men with full-time assignments to the V-2 program. In addition, a much larger number devoted a part of their time to the program. The engineering assistance received from these sources was of prime importance. These divisions also manufactured or procured the bulk of the components, equipments and supplies which were required. On many occasions assistance on special problems was received from other divisions, particularly from the General Engineering and the Research Laboratories.

8.3 GERMAN PERSONNEL

The first German specialist arrived at WSPG in October 1945 and by March 1946 German personnel numbered 39. Thereafter this number was steadily reduced; by the spring of 1947 all Germans had been replaced.

This group was undoubtedly selected with care since it included representatives of almost all phases of German V-2 activities. Among these were scientists, engineers, technicians and manufacturing personnel.

From the manufacture, test and launching of several thousand V-2 missiles, they had acquired a wealth of background experience as well as detailed "know how." This experience was passed on to General Electric personnel as rapidly as circumstances permitted. The co-operation was excellent. The exchange of information was limited at the start by language difficulties but this was overcome rapidly through the efforts of the Germans.

There is no way to assign figures to the value of the assistance provided by the Germans at the start of the program. It is certain, however, that the information received from this source was responsible for an advance of many months in the program.

8.4 MILITARY PERSONNEL

Military personnel provided assistance in many phases of the operation at WSPG. In the early stages of the program the use of enlisted men was confined, in general, to activities requiring limited skill and experience. This was necessary because of the extremely high turnover of personnel which resulted from rapid demobilization. As the situation became more stable, it was possible to utilize military personnel on more responsible work.

It was a matter of general policy to use as many enlisted men as possible to provide the maximum opportunity for training. In assembly and test, men were assigned to work directly with G-E personnel. After a time it was possible to delegate, with a minimum of supervision, considerable work on ground equipments. This work included maintenance of mechanical ground equipment, transport and erection of missiles, mixing and loading of alcohol, storage and transport of hydrogen peroxide and assistance in the loading of peroxide.

In the course of the program, valuable assistance was received from the enlisted personnel. They, in turn, received useful training and experience in the handling of large missiles.

SAFETY

9.1 HAZARDS INVOLVED

The possibility of injury to personnel is usually present during the test and launching of a rocket. By design: (1) a maximum amount of energy is stored in a minimum space, (2) propellants are selected on the basis of a violent reaction if mixed and/or ignited and (3) material safety factors are kept low.

Normally, the V-2 was loaded with: (1) 5 1/2 tons of liquid oxygen, (2) 4 1/2 tons of 75 percent ethyl alcohol, (3) 370 pounds of 80 percent hydrogen peroxide, (4) four pounds of TNT and (5) 1.7 cu ft of air at 3200 psi.

9.1.1 Liquid Oxygen

Liquid oxygen, at -183°C, would produce severe injury if allowed to remain in contact with any part of the body for an appreciable time. Ordinarily, this is not a serious hazard since lox is not usually present in open containers. Care should be taken to see that clothing, such as loose boots, does not provide pockets where lox could collect. Care should also be taken to avoid allowing a body to remain in contact with metal which is near lox temperature.

A more probable hazard is the possibility of clothing becoming saturated with oxygen gas. Such saturated clothing will ignite readily and will burn so rapidly that severe injury would certainly result.

The presence of 5 1/2 tons of oxygen in proximity to 4 1/2 tons of alcohol is a general fire hazard. More important, if alcohol and oxygen become mixed as liquids, a severe explosion may result.

9.1.2 Alcohol

A large quantity of alcohol is always a potential source of fire or explosion. Both of these hazards are increased by the presence of oxygen. Otherwise, the handling of alcohol is comparable to the handling of gasoline and introduces no additional or unique hazard to personnel.

9.1.3 Hydrogen Peroxide

Hydrogen peroxide of 80 percent purity requires very careful handling, if danger to personnel is to be avoided. Many substances will ignite immediately, if brought into contact with 80 percent H_2O_2. Perhaps the greatest hazard to personnel lines in burns from clothing set afire by hydrogen peroxide. Gross contamination by any one of many substances will cause a rapid decomposition which can reach explosive violence if confined.

9.1.4 Explosives

Four pounds of TNT were normally carried in the forward end of the V-2 for range safety and recovery purposes. Detonation was initiated through a radio cut-off receiver which applied potential to a detonator. The detonator set off the TNT through two or more strands of prima cord.

Accidental detonation of theTNT would undoubtedly cause severe injury to those working near the forward end of the missile. The damage would not be confined to this area, however, because the TNT destroys the forward end of the alcohol tank. Both fire and explosion could be expected to follow immediately.

9.1.5 High-pressure Gas

Almost two cubic feet of air was stored in the rocket at about 3200 psi. At this pressure, a break in the piping or the fracture of a storage bottle would endanger personnel.

9.1.6 Experimental Equipment

On some missiles, the experimental apparatus introduced additional hazards. This category included acid, grenades, ejection equipment and spin rockets.

On the Bumper missiles, inherent hazards of the WAC were added to those of the V-2. Any potential danger was increased by the fact that much of the servicing of the WAC took place some 50 feet above the ground.

9.2 SAFETY MEASURES

The potential dangers involved in the servicing and launching of the V-2 were recognized to some extent. A determined effort was made to minimize any potential danger. It was obviously impossible to appraise any particular hazard and draw a precise and accurate line between safety and danger. It was, therefore, a matter of policy to "lean-over backward" in the direction of safety in the hope of staying outside the questionable zone. During the course of the program, safety measures were adopted or developed as rapidly as the need appeared. Many of these measures were common practice industry. Others were developed to meet special conditions.

9.2.1 Liquid Oxygen

For some missile hazards, there are mechanical aids which may be used to advantage. For liquid oxygen, however, vigilance is the primary protection. This starts with assembly and continues until the missile is launched. There must be assurance that: (1) the tanks and piping are mechanically sound and have no leaks (2) the system is clean and contains no combustible substance or any substance which is shock-sensitive in the presence of lox (many anti-seize compounds are dangerous in this respect), (3) the system contains no mechanical parts which will become excessively brittle at lox temperature and (4) there is adequate freedom of motion to allow for contraction. At the launching site, a careful watch must be maintained so see that: (1) there is minimum exposure of personnel to liquid or gaseous oxygen, (2) combustible materials are present only as absolutely required, (3) sources of ignition are kept to a minimum (no smoking, soldering, drilling and use vapor-proof drop lights in or near missile) and (4) the oxygen tank vent remains open at all times after lox loading starts.

9.2.2 Alcohol

Protection against injury to personnel by an alcohol fire or explosion consisted of reducing to a minimum the possibility of: (1) the alcohol coming in contact with an oxidizer, (2) the accumulation of alcohol vapor and (3) ignition. In the normal operating procedure, neither lox nor H_2O_2 was present during alcohol loading. A drip pan was used at the alcohol tank inlet to insure that no alcohol could fall within the missile. Firemen stood by to dilute and wash away any outside spillage. After loading, a very careful check (using a vapor-proof light) was made to insure that there were no leaks within the missile. An effort was made to keep possible sources of ignition to a minimum.

9.2.3 Hydrogen Peroxide

Hydrogen peroxide was stored in an air conditioned (by evaporation cooler) pill box in an isolated location. Thermocouples were provided to determine the temperature of each drum before personnel entered the storage room. Standard procedure called for daily inspection.

In the normal-German loading procedure, H_2O_2 was first placed in a pumping unit from which it was hand pumped to a measuring container. From there, it was gravity-fed to the missile tank. To avoid unnecessary handling (with the attendant possibility of contamination and spillage) a new procedure was adopted. The original H_2O_2 shipping drums were hoisted to an upper level of the crane and placed in an aluminum pan. From there, the H_2O_2 was gravity-fed directly into the missile tank. Thus, external sources of contamination were reduced to one short section of hose.

The missile tank, itself, was a possible source of trouble. The tank, made of steel, was lined with a protective coating. One tank began to cause some decomposition of H_2O_2 after being used 13 times at the calibration stand. Inspection showed that very little of the protective lining remained. A series of tests indicated that even with this used tank, the decomposition rate was not rapid enough to constitute a serious hazard. Similar tests on an unused tank showed practically no decomposition. Although these tests indicated that considerable reliance could be placed on unused German tanks, three safety measures were practiced: (1) the protective coating of the tank was carefully examined, prior to assembly, (2) during and after loading, the tank was checked frequently by hand to detect any appreciable rise in temperature and (3) a quick-action valve was connected to the outlet of the tank. A hose from this valve led to a tank containing enough water to provide about 15 to 1 dilution. Thus, the tank could be drained quickly and safely at the first sign of trouble. During H_2O_2 handling and loading, full suits of protective clothing, including helmets, were worn. These suits had one undesirable feature, being impermeable by design, they allowed very little air to enter. On a hot day it was necessary to remove the hood at about ten-minute intervals.

9.2.4 Explosives

In the explosive system, the most probable source of trouble was the electrically fired detonator used to detonate the TNT through prima cord. A relatively small amount of energy was required to fire this detonator. Several steps were taken in an attempt to prevent the detonator from being fired through induced potential, electrostatic potential, leakage or direct contact. The circuit was isolated as far as possible. No terminal blocks were permitted in the circuit and connectors were kept to a minimum. A separate, ungrounded battery of 67.5 volts was used. A time-switch contact held the battery circuit open until 20 seconds after take-off.

Another protective feature was a short-circuit across the detonator. This was completed through a pull-away plug so that it remained effective up to the instant of lift. Heavy wire was used to keep the resistance low and to withstand high current in the event of direct contact. It was intended that the current-carrying capacity of the short would be greater than that of any other wires connecting to the detonator. In addition, a dropping resistor was connected directly ahead of the detonator and short.

A different type of short-circuit was used at the end of the program. A small motor, controlled from the blockhouse, was used to open and close a heavy-duty switch. This switch was connected across the detonator by very heavy wires about six inches long. The position of the switch was monitored. It is believed that this switch arrangement was better in that it provided a minimum of resistance and a minimum of exposure to direct contact or pickup.

Various safety procedures were followed during and after installation of the detonator. The installation was scheduled as late as possible to minimize the time of exposure. A radio-silence and no-switching period was established before the installation was started. The wires to be connected to the detonator were tested to ground with a megger and were tested with a voltmeter to see that there was no voltage between wires or from either wire to ground (before and after this test, the voltmeter was proved operative by connection to a dry-cell). The open-circuit resistance between wires was measured and the value of the dropping resistor checked. Resistance of the short-circuit was measured. The short was removed and replaced to insure that the value measured was actually that of the protective short. Thereafter, the access port to the short was locked to prevent tampering. All of these checks were witnessed by a second person.

Immediately after these checks, the detonators were connected in the circuit. While being connected, they were housed in a strong, steel safety box in which suitable vents were provided. Thus, no injury would result if they should fire at the instant of contact, which was one of the more probable occasions. After the connections had been completed, the detonators were removed from the safety box and taped to the prima cord.

Beginning in December 1949, the detonators were housed in a destructor block which offered added protection. This device was developed by the Naval Ordnance Test Station. The design was such, that when the destructor block was in the disarmed position, the firing of the detonators would not detonate the prima cord and TNT. It was armed by withdrawal of a safety wire when the cast-off plugs fell. The destructor block was regarded as an additional safety measure and not as a replacement for those measures previously used.

At times it was necessary to return to the missile for further work after all normal launching preparations had been completed. On such occasions, the first step was to remove the detonators from the prima cord and to disconnect them from the blow-off circuit.

9.2.5 High-pressure Gas

In general, the high-pressure lines within the missile were of small diameter and adequate wall thickness to offer a reasonable safety factor.

Since the strength of the storage bottles was less obvious, three bottles were tested to destruction. There was remarkable consistency both in the failure pressure and in the type of rupture. The failure pressure was nearly twice the working pressure and failure was by a split in the tank rather than by fragmentation.

Prior to assembly, all storage bottles were tested hydraulically at 4500 psi. Although these tests gave moderate assurance of safety, one further safety measure was followed. The pressure in the missile was not brought above 2700 psi, until the missile was cleared for launching. On occasion, it became necessary to return to the missile after the bottles were charged to 3200 psi. This was undesirable, but could not be avoided.

Experience leads to the conclusion that flexible hose offered greater safety than copper tubing for temporary high-pressure test connections. Copper tubing tends to work-harden after a few bends and appears to be more susceptible to damage. Standard procedure called for periodic tests of all flexible hose. To avoid excessive "whipping" in the event a fitting (at the end of a high-pressure hose) was lost, an anchoring device was utilized. A clamp was attached to the hose a few inches from the end fitting and a short chain used to secure this clamp to the closest suitable anchorage.

9.2.6 Gantry Crane

Many of the preparations for launching were made at 40 feet, or more, above the ground. A gantry crane (Fig. 27) was provided by WSPG for this work. Safety-wise, the crane offered many advantages over the German field equipment, but a few problems still required attention. Since it was necessary for men to work at the bottom of the missile while others worked at the top, one of the most common dangers was falling objects. Personnel were urged to use care in handling tools and equipment overhead. Side boards were added to the gantry platforms to keep objects from rolling off or being pushed off. A safety net was suspended below the upper platform and "hard hats" were worn by those working on the ground.

In the course of the program, it became evident that the regular ladders on the gantry might not provide a safe escape route in the event of certain troubles, such as a burning V-2 (never occurred at WSPG). An escape cable, with sliders, was secured to an upper platform and was anchored to a post located about 200 feet from the gantry. This provided a means of escape which was fast and which continually increased the distance between the missile and the man.

It was apparent that if a man were severely injured on the upper levels of the crane, it would be extremely difficult to get him to the ground by way of the ladders without aggravating the injury. To meet this problem, special stretchers were obtained. These were designed so that a man could be strapped in securely and lowered by one of the gantry hoists.

On occasion, it was necessary to move the gantry, under power, until a fixed platform came within a few inches of the erected missile. It was conceivable that a mechanical or electrical failure in the control equipment might cause the crane to continue in motion and push the missile from its stand. To provide for this possibility, a master disconnect switch was located within easy reach of the crane operator. During close operations, the operator was instructed to keep one hand on this switch.

Fig. 27 A Gantry Crane Facilitated Work on The V-2 at WSPG

9.2.7 Launching Area

A warning siren was installed to clear the launching area in case of danger. Siren switches were located at suitable points in the area.

Standard Proving Ground procedure called for an ambulance and one or more fire trucks to remain within the area when launching preparations were in progress.

9.2.8 Component Testing

Testing of the propellant tanks required caution.

Although the tanks were of considerable volume (162 cubic feet each) they were of light construction, made of an aluminum magnesium alloy. Wall thickness of the oxygen tank was 0.08 inch and the alcohol tank 0.048 inch. Of the two, the oxygen tank was probably more dangerous since the alcohol tank had a tendency to pull rivets and relieve itself.

The potential danger of the oxygen tank was demonstrated in a destruction test. The tank top blew out at 52.6 psi and the tank traveled 8 feet before striking a guard rail. A two-inch iron pipe upright (set in concrete) was broken and a 14 1/2 foot section of double two-inch pipe railing bent outward. Pieces of tank were thrown 150 feet.

Since the oxygen tank was pressurized to 21 psi at the launching site, it was necessary to test it to a higher value prior to assembly. Hydraulic tests at 32.7 psi were made in a cleared area, outside the Mill Building. These were followed by an air test at 21 psi within the building. During the latter tests, the following precautions were taken: (1) all personnel, other than testers, were cleared from the area, (2) a relief valve was installed on the tank, (3) two independent gages were used to indicate tank pressure, (4) gages were observed through a slit in a heavy steel barrier and (5) one man remained at the supply valve until the tank had been charged and the supply hose disconnected.

9.3 SAFETY RECORD

This report covers a period of 69 months. During this period, the average number of G-E personnel stationed at WSPG was 29. Total lost time for this group due to accidents was 9.5 man-days.

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APPENDICES

To avoid repetition of material already available in other reports, the appendices are written on the assumption that the reader is well informed on the V-2 system or has access to: (1) General Electric Company – Project Hermes report DF-71369, "The Missile A-4 Series B" February 1, 1945 (called A-4 Manual for brevity in appendix references) and (2) British Special Projectiles Operation Group, "Report on Operation Backfire," November 7, 1945 (called Backfire for brevity in appendix references).

APPENDIX A
PROPULSION SYSTEM COMPONENTS

A.1 OVER-ALL SYSTEM

It had been mentioned by some of the German personnel that after the V-2 went into production it was very difficult to have any changes made. There were two reasons given for this: first, changes necessarily slowed-down production and, second, (and this reason was referred to time and time again), since they already had a missile that would fly, they were hesitant about changing to something that had not been flight-proven. Thus, many changes and improvements that were developed and tested were never used on a missile. Two examples of this are the removal of the check valve in the steam generator and the incorporation of the heat exchanger into the turbine. Both of these changes were worked out and tested, but were never used.

However, a great number of changes were made after production had started, as indicated by the many different types of components received at WSPG and by the differences in components received at WSPG compared to the descriptions and pictures in the German A-4 manual. This includes valves, steam plant, steam plant piping, turbine, and propulsion piping. Possibly some of these differences were due to the fact that more than one factory made the same component; however, many differences could not be explained in this manner.

The propulsion system had been fairly reliable and was (in most respects) well designed. However, both main valves and the lox vent valve were considered to be designed wrong; it is felt by WSPG launching-personnel that these valves should have been designed to be fail-safe pneumatically for personnel (closed with pneumatic pressure in the case of the lox vent valve, and vice versa in the case of the main valves).

The lox tank pressurizing valve and pressurizing control switches were not flown but were left on the stand; this was a step in the right direction, as was the design of the lox topping arrangement (following remote topping and draining while adding only one check valve as a flyable component). The control for the opening and closing of the valve was left on the ground.

In only one application (the large seat of the lox main valve) did the Germans use anything but a metal-to-metal seat for the sealing of liquid oxygen. Considering the amount of trouble experienced at WSPG with leakage past these metal-to-metal seats, it is possible that such an arrangement was used simply because the Germans had no suitable sealing material for use with liquid oxygen. A WSPG test, though inconclusive, indicated that the rubber-like seat used on the lox main valve was not sealing well with liquid oxygen. It is possible that an alignment problem was the reason this seat was not also of the metal-to-metal type.

It was obvious the V-2 was not designed with an eye toward easy repair in the field. Access hatches were placed only where necessary for fueling and de-fueling and for last minute adjustments. This was probably part of an over-all policy decision of allowing a minimum of time on the launcher, whether launched or not. Conversely, access for hangar repair was very good, since the removal of the tail took only about an hour and allowed maximum accessibility of all parts. The design of the steam plant as a sub-assembly allowed the complete unit to be changed in a very short time and made it possible to test it as a separate unit. This arrangement also made possible a speedier initial assembly of the missile, which of course reduced the over-all assembly area needed. Furthermore, the propulsion section itself was a sub-assembly, so there was no necessity of bringing it into the main assembly area with the midsection, control section, and tail (also sub-assemblies) until it was tested and ready.

A.2 COMPONENTS

A.2.1 Jet Vanes

Approximately 20 percent of the vanes were discarded because of faults discovered in the examination of the X-rays. These faults included cracks, voids, surface holes, inclusions and porosity. A number of vanes had stripped holding threads and could not be used.

The carbon vanes may be divided into two general types: the mill-marked type, and the smooth or non-mill-marked type. According to a German specialist these two types were manufactured to different specifications. The smooth vanes were softer and showed a greater tendency to pull away from the backing plate. Conversely, the milled vanes were more brittle and more likely to break off in the jet. However, the Germans considered both types suitable for firing.

To verify this information, the studs holding the vane to the backing plate were torqued down until the carbon threads failed on a number of unflyable vanes. It was found that the threads in the smooth vanes pulled out at a lower torque than did the threads on the milled vanes. It was also found that vanes with the prefix or suffix "712" in the serial number withstood the greatest torque of all vanes. The results were:

Minimum torque necessary to strip threads: Zero (probably stripped prior to test).

Maximum torque necessary to strip threads: 570 inch-pounds

Average torque necessary to strip threads: 270 inch-pounds

Average torque necessary to strip threads on smooth vanes: 200 inch-pounds.

Average torque necessary to strip threads on mill-marked vanes: 290 inch-pounds.

Average torque necessary to strip threads on mill-marked vanes with a prefix or suffix "712" in the serial number: 340 inch-pounds.

Average torque necessary to strip threads on mill-marked vanes that do not have a prefix or suffix "712" in the serial number: 230 inch-pounds.

Some carbon vanes had red or white stripes approximately 1/2 to 1 inch wide painted on each side. This marking was a German code. White paint indicated that the vane was satisfactory; red paint indicated that the vane was unsatisfactory and should not be used.

Carbon vanes were classified A, B, and C. Class A and B vanes were suitable for firings; class C vanes could be used only for static tests. Although originally classified in Germany, vanes were later X-rayed and classified in the United States. The following are instructions for inspection and classification of vanes:

a. Any unusual appearance should be noted and, if possible, correlated with visual inspection of the vanes. The inspector should be especially careful to look for the following faults:

1. Porous material gives a filamentary appearance to the negative, as if heavy lint were on it
2. Cracks show up as thin dark lines on negative
3. Voids, Chipped Plates, Surface Holes appear as dark spots on negative
4. Inclusions appear as light spots on negative

b. Faults should be characterized as "weak," "distinct" or "prominent," and in some cases as "round," "elongated," or "irregular." The sizes of round areas should be described as follows:

Smaller than 1/32-inch diameter..."very small"

1/32 to 1/8-inch diameter..."small"

1/8 to 3/16-inch diameter..."medium"

3/16 to 1/4-inch diameter..."large"

Larger than 1/4-inch diameter..."Very large"

In the case of elongated or slightly irregular faults, the sizes should be described as for a round fault of equivalent area.

c. The location of a fault is also important, particularly if it is in a critical area, such as the leading edge of the main part of the vane or of the toe, particularly near the outboard corners. The descriptive terms in Figure 28 are suggested.

d. Although not intended to eliminate the need for exercising judgment in each individual case, the following rules are offered as a guide:

1. Class A (Excellent): This class of vane contains no "large" voids or inclusions, nor more than three "medium" or "small" voids or inclusions unless these are weak and not located in a critical area. The vanes may contain a large number of "very small" speckled inclusions.

2. Class B (Second Choice): This class of vane has more or larger defects than A vanes, but none are located in critical areas, the vane otherwise being satisfactory.

3. Class C (Questionable): Any cracks or noticeable porosity, as evidenced by filamentary appearance places vanes in this classification. "Very large" voids or inclusions, "medium" or "large" voids or inclusions in critical areas, "small" prominent voids in critical areas, or any unusual appearance which cannot be explained by visual inspection will also place vanes in this category.

The Germans were not greatly worried if the carbon side strips were defective, i.e., if they had one or two inches chipped off one end. It was the policy at WSPG, however, to change these strips if they were broken.

The clearance between the vane and the backing plate had to be at least the thickness of ordinary writing paper, or the vane could not be used.

The carbon vane holding studs were torqued to 110 inch-pounds both before and after the load test. They were tightened beforehand so that all studs would take an equal load and were tightened afterward to make sure there had been no failure of the threads.

Not earlier than one month before the firing date, the vanes were given a static load test by applying 2300 pounds on one side of the vane, then turning the vane over and applying the same load on the other side. A special machine was used for this test. The 2300-pound force was obtained by using a 224-pound weight and a lever arm. The force was applied longitudinally over 8 inches of the vane, 6-1/2 inches from the outer edge of the backing plate. Of course, measurements or computations were not necessary during the test; the vane was simply bolted into place on the machine, and the weight gently lowered. No vanes were broken at WSPG during this test, but the test probably detected weaknesses in some holding threads, since a few stripped threads were detected after the test had been run.

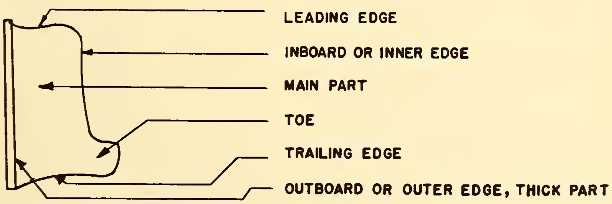


Fig. 28 Jet Vane Descriptive Terms

The Germans considered that a vane was still useable for a firing even if the threads for one holding stud were stripped, provided the defective part was located on the lower half of the vane. The policy at WSPG, however, was not to use such a vane if other "A" or "B" vanes were available.

To minimize the danger of breakage, vanes were not installed on the missile until the day of the launching.

It was the policy at WSPG to discard vanes which had been exposed to flame by a misfire. The possibility of the vanes being damaged by the flame was small, so the procedure was merely precautionary. As time elapsed after the firing, however, it became more important to change the vanes, since the vanes were hygroscopic and could have absorbed moisture after the protective lacquer coat had burned off. This moisture might have caused the vane to break open as it turned to steam in the jet. It was felt that the vanes should definitely be changed if they had been sprayed with water at any time or if they had been sprayed with CO_2 while hot.

When vanes were put on the missile, a notation was made of the serial numbers and the corresponding fin numbers. Thus, if a vane fell off and was recovered, it might have been possible to determine which fin it had been on.

Just prior to firing, the vanes were covered with a 3/32-inch thick cardboard envelope which was lightly wired in place. This was a precautionary measure to protect the vane from the possible impact of the igniter as it was expelled from the burner. These covers were expelled from the burner prior to lift.

It is believed that on one occasion a missile failure was caused by a piece of a vane, or a complete vane, breaking off. This incident occurred before vane covers were used and before X-rays and load tests were made.

Although vanes were considered fragile, and were always handled as such, on some occasions vanes were found intact at impact. In these cases the warhead had been blown off and the tail section had landed on one side. Thus, the vanes that survived had not come into contact with the ground.

A.2.2 Burners

References: A-4 Manual, pp. 17, 88, 101, 105a, 105b and 223; Backfire, Vol. II, pp. 19, 20, 21, 25, 30, 89, 113, 114 and 115.

An attempt was made at WSPG to boost the cooling jacket test pressure from 255 to 325 psig. This resulted in the rupturing of the inside-dome wall in three of the four burners tested at the higher pressure. The following information was obtained from conversation with German personnel:

a. It was possible to tell, by visual inspection, which burners had been static fired. Static firings left darkened streaks on the alcohol nozzles, and, because of the temperature differences, left discolored areas around the ZK nozzles and the cooling nozzles.

b. Test runs were made with the upper row of film cooling-holes blanked off and it was found that this row was not necessary.

c. Practically all burner failures detected because of static firings occurred on the inside of the burner. Of these, some inner walls bulged inward, but most failed on one of the inside wall welds.

d. At first, burners were manufactured with only two expansion folds in the outer wall, and with no expansion loops in the cooling supply lines. It was later found that with this design, unequal expansion of parts was still causing failures; in subsequent missiles another expansion fold was added and expansion loops were put in the cooling lines.

e. All burners used by the Germans for flight purposes were static fired. Because of the expense involved in static firings, a series of tests was made to determine if powered-flight conditions could be duplicated. In these tests, burners were subjected to extreme vibration while pressurized. The burners were then inspected, and if no cracks or other faults had developed, they were static fired. Since some burners that had successfully passed the vibration-pressure test developed cracks when static fired, it was decided that such a test was not adequate. If these tests had proved successful, it was planned to affix a plate to the throat of the burner, and pressurize the upper combustion chamber at the same time the outer shell was tested. This would protect the inner wall of the dome from excessive pressures while giving the outer jacket a high pressure test. The throat instead of the outlet would have been used for blocking because it was believed that the lower part of the burner would not withstand the necessary internal pressure.

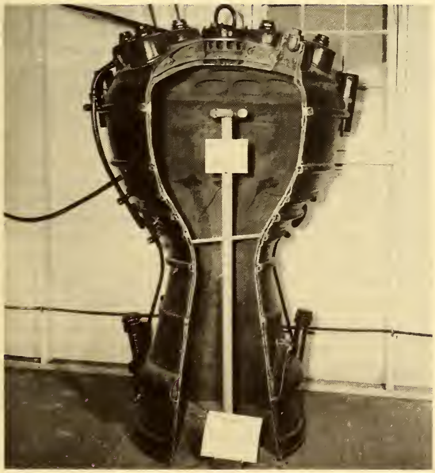
f. During the latter part of the program, burners were static fired for only 10 seconds. This procedure was initiated after it was found that practically all burner failures occurred during the first few seconds of test.

g. On the first burners manufactured, there was no covering on the bottom skirt of the burner. It was later found that this skirt was reaching a temperature sufficient to ignite alcohol that often leaked from loose couplings. A sheet metal cover with glass wool insulation was then added, which greatly reduced the number of tail explosions.

Applying a hot-air blower to remove moisture from a burner would often damage the ZK nozzle plastic gaskets sufficiently to cause a gas leak when the burner was later pressurized. When burners with ZK nozzles installed were hydrostatically pressurized to the 255-psi test-value, Wood's metal in the nozzles would often blow out. This necessitated the use of blank ZK nozzles for such tests. In almost every case in which a missile reached preliminary stage and did not subsequently take off,it was found that the Wood's metal had melted out of some of the ZK nozzles and alcohol was leaking into the combustion chamber. When this happened (and it was still possible to fire the missile) the holes were plugged with sharpened pieces of wood or matchsticks.

One burner, after having been flight-tested was found to have a small hole burned completely through the inner jacket. This was caused by a plugged hole directly above it in the cooling ring. At least one other burner showed evidence of eroding, but the burner metioned above was the only one noted in which a hole had been burned through the jacket.

Many of the burners at WSPG had mounting brackets knocked out of line, cooling lines mashed and expansion joint fittings and cooling line fittings (Fig. 29) knocked off. Almost every burner used had some defect requiring a welding-repair. One burner used at WSPG had a flattened main valve seating ring. This was probably caused by mishandling some time after manufacture. In addition to these defects, some burners had to have loops welded into the cooling lines. Also, some sheet metal skirt covers were rusted through, and had to be repaired or replaced.



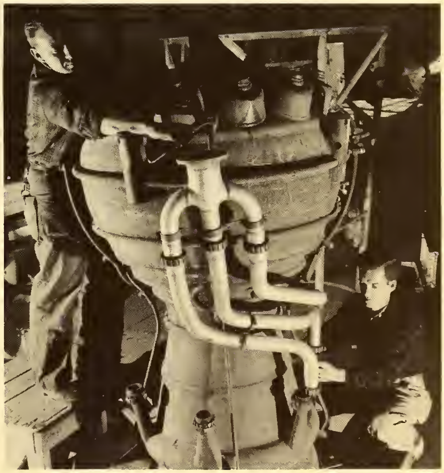


Fig. 29 Cutaway of V-2 Burner (left) and Burner-piping Installation (right)

All missiles fired at WSPG had paper cups installed over the oxygen nozzles. These cups were used "In order to prevent a premature mixing of the oxygen and alcohol which would cause local explosion on ignition, or freezing...."[11] German personnel believed these cups were used to keep oxygen fumes out of the upper alcohol chamber of the burner. Any oxygen that leaked past the lox main valve would be directed downward away from the alcohol nozzles.

A.2.3 Gas Bottles

References: A-4 Manual, p. 17 and 80; Backfire, Vol. II, p. 22 and 23.

To obtain an indication of the weight and volume range of the air bottles a small number of bottles were weighed and volume measurements taken. The weight varied from 18 to 21 pounds, and the volume from 7.04 litres to 7.45 litres.

Five sets of bottles on hand at WSPG had been wound with wire; they weighed between 20 and 21 pounds each. According to German personnel, these were experimental bottles never used on the V-2. Three were hydrostatically tested to rupture. The wires began to break at 7000, 7100 and 7750 psi; final rupture was at 4200, 4500 and 7000 psi. In all cases, the rupture was a longitudinal break in the side of the bottle.

During the firing program it was discovered that some of the air bottles were rusty inside. After that, before any bottles were used in a missile, the manifolds were removed and each bottle was checked for cleanliness. If a bottle was rusty, the rust was removed. This was accomplished, after some experimenting, by removing the bottle adapter, filling the bottle about 30 percent full with Mecha Finish #4, filling the voids between the Mecha Finish particles with water, and rotating the bottle for two hours. The rotating mechanism was designed so that the bottle could be tilted at intervals during the cleaning process and thus clean the ends of the bottle. After the two hour cleaning period, the Mecha Finish was removed and the bottle was water flushed and dried. Mecha Finish #4 was an abrasive rock-like material distributed by the Mecha Finish Corporation of Sturgis, Michigan. The pieces had to be broken apart before they were small enough to be put into the bottles. Prior to the time that Mecha Finish was used to clean the bottles, scrap nuts and screws were used. Although this did not clean the bottles as well as did the Finish it did remove most of the rust.

After the bottle cleaning program was started, it was found that most of the manifold nipples were being deformed during retightening, many to the extent that there was concern that they might possibly pull through the nut. New nipples were made to replace the German units. The German nipples were cut off at the original weld and the new nipples were slipped over the manifold tubing and lap welded. The curvature of the seats remained the same as before, but the nipple shoulder was made slightly wider. The distance between the shoulder and the seating circle was made shorter, so that a maximum of threads could be utilized. On a few manifolds, the nipples were not being deformed. These manifolds were easily detected beforehand, since they were painted a color different from the others.

Bottles, with adaptors installed, were hydrostatically pressurized to 4500 psi after they had been cleaned. Manifolds were also hydrostatically pressurized to 4500 psi. During most of the program, the assembled bottles and manifolds were pressurized to 3500 psi. During the latter part of the program, however, only 3000 psi test air was available. It was considered safe to use bottles tested to this pressure, however, since they had previously been tested hydrostatically to a much higher pressure. On no occasion did an air bottle fail in test, except in cases where the purpose of the test was to find ultimate strength. There were occasions of leaks in manifold welds and at connections, but no leakage was ever found through the bottle proper.

A.2.4 Heat Exchanger

References: A-4 Manual, p. 17, 88 and 139; Backfire, Vol. II, p. 25 and 32.

Oxygen flow through the heat exchanger was about 0.3 kg per sec, according to German personnel and the A-4 Manual.

A test was run at WSPG on each unit to determine if the orifices in the orifice block were of the correct size. This was determined by applying a constant air pressure (7.1 psi) to the liquid side of the unit and allowing the air to exhaust to atmosphere while measuring the flow by means of an orifice and manometer. A flow deviation of about 10 percent above and below the optimum flow was allowed. In many instances, this flow range could not be met and the orifice block was replaced with a block made at WSPG.

All cases were hydrostatically pressurized to 28 psi. No leaks were found in any case.

The tubing coils were pressurized to 71 psi. A number of coils were found with pinhole leaks.

According to one of the Germans, a heat exchanger was designed to fit inside the turbine. This was never used on a missile.

It was reported that the Germans had considerable difficulty with pressure fluctuation on their first heat exchanger models. It was finally determined that oxygen gas was forming an insulating coating on the inside of the tubes, and a slight jar would disturb the coating, causing a sudden increase in gasification, and therefore, a pressure surge. This problem was solved by constructing and mounting the heat exchanger coils in such a manner that they would vibrate easily. Thus the missile vibration was enough to keep the gas film broken up, resulting in a fairly constant gas output.

A.2.5 Lines and Fittings

References: A-4 Manual, p. 52 and 114; Backfire, Vol. II, p. 18 and 19.

Beginning with missile 56, all lox and alcohol pressure lines and fittings were hydrostatically tested to 500 psi. On missiles prior to this time, the lines and fittings were checked for leakage, but not for strength. It was found that the American-made alcohol three-fold couplings would not withstand the 500-psi hydrostatic test pressure. Two were tested and each ruptured at a crotch weld at 410 psi. These two, and all other American-made alcohol three-fold couplings were returned for re-welding. It was found that the German-made alcohol three-fold couplings on hand would withstand the 500 psi hydrostatic test-pressure without failure. Only German couplings were used throughout the rest of the program. About 15 percent of the American-made alcohol feed lines leaked air when pressurized to 100 psi. About 50 percent leaked air when pressurized to 100 psi after a 500 psi hydrostatic test. This indicated that 500 psi was opening the welds, although in no case was there any noticeable sign of cracks in the welds, except in cases where such cracks were evident before any tests were run. It is possible that the holes in the welds were plugged with flux or oxide and a pressure higher than 100 psi was necessary to clear them. In some lines, there was leakage in cracks alongside the weld, but these cracks were evident before any tests were run. In no instance was there leakage at any place except in or alongside a weld. In most instances, the leakage was at a pronounced crater in the weld, or at a spot where a weld had been ground down. One representative line was returned to the vendor, the others were repaired at WSPG.

In contrast to the alcohol feed lines, the American-made oxygen feed lines had smooth welds, and less than five percent leaked when subjected to the same tests given the alcohol feed lines.

The live steam line and the lines from the alcohol two-fold fitting to the alcohol three-fold fitting were too rigid to allow bending for alignment with mating parts. Since these lines were stocked disassembled (i.e., flanges not welded on), the procedure for mounting was to bolt the flanges in place, cut the line to size, and tack weld the line to the flanges. The assembly was then removed and the weld completed in a more convenient location.

The stripping of threads on the lox three-way couplings and the lox lines was at first quite serious. Removal of these lines to facilitate the removal of the lox main valve resulted in damage to 40 to 50 percent of lines and couplings on the first two or three calibrated units. Later it was found that the lines could be sprung back sufficiently to allow removal of the lox main valve; this procedure was followed on the remaining units.

The live steam line was hydrostatically tested to 600 psi. The line, including all protuberances, was insulated by lagging with asbestos and coating the asbestos with water glass. Flanges were insulated by covering with glass wool or glass rope held in place by sheet metal covers. Many air lines for the missile had to be made up at WSPG. These were made of copper tubing with steel silver-soldered fittings.

A.2.6 Turbo pump

References: A-4 Manual, p. 59, 69, 71, 73 and 222, Backfire, Vol. II, p. 18, 27, 29 and 111.

a. Cleaning

During the first part of the firing program, pumps were cleaned by pouring water into the alcohol pump and carbon tetrachloride into the oxygen pump and allowing the liquid to stay in the pumps for about 30 minutes, agitated frequently by rotating the unit. The pumps were then dried with a hot-air blower. As the program progressed and units were calibrated, the pumps were cleaned by wiping when disassembled, then, after final assembly, carbon tetrachloride was poured into the lox pump and allowed to set for about 30 minutes to thoroughly degrease all parts. The pump was then dried with a hot-air blower. This procedure was followed until a shaft in a turbine that had been assembled for about six weeks was found to be frozen. Disassembly showed that the steel parts in the lox pump were very badly rusted. From that time until the end of the program, all cleaning was done by wiping while pumps were disassembled, except that the lox pump was filled with carbon tetrachloride and soaked for about 30 minutes before final disassembly to degrease parts that would not be accessible for hand cleaning after disassembly.

b. Disassembly Policy

If turbopumps were disassembled at all during the first part of the firing program it was only to the extent necessary to decrease leakages. Later in the program when calibration of propulsion units was initiated, all turbopumps were disassembled after calibration to dry and to clean residue off the turbine parts. Shortly after that time, it became standard routine to disassemble all turbines before calibration, and use only those turbines which appeared to be easily repairable in the event a part should become defective during calibration. Such disassembly was considered advisable on other grounds also, since an increasing amount of foreign matter was being found in turbopumps.

c. Corrosion

No rust or other corrosion was ever noticed in a turbopump until after it had been calibrated. The first few turbines calibrated were very badly rusted when disassembled. The procedure at that time was to dry the complete propulsion unit with a hot-air blower before the turbine was disassembled. Often a week or more had elapsed between the calibration run and the disassembly of the turbopump. Later in the program, the turbopump was removed from the unit immediately after the run, and was, in most instances, completely disassembled. Each steel and iron piece was dried the same day the calibration run was made. Even with this procedure, there was some rusting. When the turbopump was allowed to set even overnight without being disassembled, considerable rusting occurred.

Alcohol pump:	
Outside diameter of impeller	12.74 inches
Inside diameter of case	13.4 inches
Number of vanes	seven
Thickness of vanes at outlet	0.22 inch
Outlet angle of vanes	32 degrees
Width at outlet	0.6 inch
Inside diameter of inlet	5.92 inches
Oxygen pump:	
Inside diameter of impeller	10.53 inches
Inside diameter of case	10.6 inches
Number of vanes	seven
Thickness of vanes at outlet	0.15 inch
Outlet angle of vanes	18 degrees
Width of outlet	0.66 inch
Inside diameter of entry	5.57 inches
Turbine:	
Mean diameter of blades and nozzles	18.5 inches
Number of nozzles	16
Throat area per nozzle	0.059 inch
Mean height of nozzles	0.04 inch
Mean pitch of nozzles	1.6 inches
Outlet area per nozzle	0.21 square inch
Nozzle angle	20.5 degrees
Stationary blades:	
Number – 4 sets of 28	112
Height at inlet	0.68 inch
Height at outlet	0.83 inch
Pitch	0.32 inch
Outlet area (per segment)	3.6 square inches
Outlet angle	28 degrees
Moving blades:	
First row –	
Height at inlet	0.63 inch
Height at outlet	0.63 inch
Pitch	0.32 inch
Blade inlet angle	24 degrees
Blade outlet angle	24-26 degrees
Second row –	
Height at inlet	0.98 inch
Height at outlet	1.10 inches
Pitch	0.32 inch
Blade inlet angle	30 degrees
Blade outlet angle	26-28 degrees

Fig. 30 Technical Data on V-2 Turbopump Assembly

One lox pump had rusted so badly that the shaft could not be rotated. This pump was supposedly ready for launching and had been assembled to its turbopump for about six weeks when the condition was discovered. It was never determined what caused the rusting. A lox pump that had never been calibrated was given an identical cleaning treatment and was found not to have rusted after two months storage. Some possible damage to the protective coating during calibration might have caused the rusting in the lox pump mentioned first, but the most logical explanation is that a considerable quantity of water had mixed with the carbon tetrachloride used for the final degreasing. From paragraph 1422 of the A-4 Manual, "The steel parts (of the turbopump) are protected against the action of moisture by a special polishing and hardening process using corrosion protective oil. The lox pump is specially degreased during the last test run at the supply firm." Since water was never admitted to any lox pump until it was on the calibration stand, it is not known what effect large quantities of water (but no calibration) would have on the special-process parts.

No rusting of parts occurred in the alcohol pump since all steel parts were thinly coated with grease in Germany. The seals on the alcohol side of the turbine rusted appreciably on only the first few turbopumps calibrated; on later turbines the seals were coated with a thin film of grease during the initial disassembly. The seals on the lox side of the turbine were not coated with grease because of their close proximity to the lox pump.

Turbine and lox pump seals were cleaned by using crocus cloth. Fine emery cloth was used on the other steel parts in the lox pump.

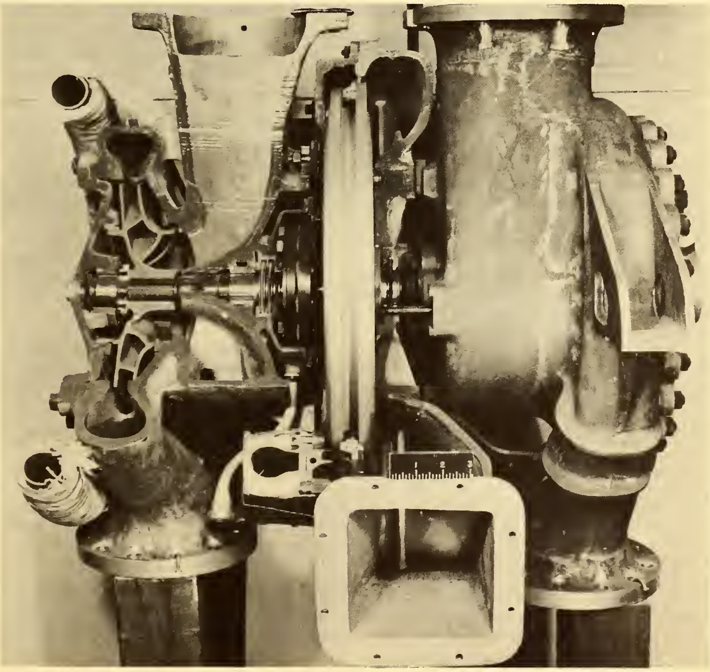


Fig. 31 Cutaway View, V-2 Turbopump Assembly

d. Further Effects of Calibration

The first two or three turbopumps that were calibrated showed considerable erosion of the turbine buckets. Subsequent reduction of the steam temperature completely eliminated this erosion.

All turbopumps had permanganate residue left in the turbine after calibration. Most of this was removed with wiping cloths and a wire brush, although no special effort was made to make the surfaces completely clean.

On many turbopumps, the turbine and lox seals held pressure better after calibration than before calibration. This was probably caused by the wearing-in of the seals, or, in some cases, by the fine rust that was formed on the seals.

e. Component Difficulties

Since many turbopumps were available at WSPG, the units which could not be repaired easily were not used; the parts were stocked as spares. Included in this category were turbopumps that: (1) did not have an alcohol return line fitting, (2) had lox seals different from the usual seals, (3) had defective parts, and (4) had leakages difficult to correct.

The iron seals on the turbine and lox pump gave much more trouble than did all other components. During the first part of the program, leaky seals were repaired. The sides and ends of the seal segments were, where necessary, ground-down with a fine stone, and then lapped. The inside radius was ground down by using lapping compound between the segment and the corresponding cylindrical part from a discarded turbine. Such repair work was very time-consuming, therefore, as the program progressed and spare parts were accumulated, seals were replaced instead of repaired. During the latter part of the program, virtually no seals were repaired. A large stock of spare seals was necessary, since as many as a dozen seals might be tried before one was found that would fit a particular shaft.

Another cause of leakage past the turbine seals was distortion of the seal plates. In most turbines, these plates were fairly thin and some would be badly distorted. The plates were replaced when better spares were available. If better units were not available, the distorted plates were "trued" on a lapping plate or by using a bearing scraper. Defects were found by using a surface plate and "Prussian blue." Even if "trued-up," the plates would often distort when tightened on the turbine. A few of the turbines had extra-thick seal plates. These plates were quite superior to the thin ones, since they could be put into place very tightly without distortion.

In many turbines, the area on which the seal plate seated had been raised at the tapped holes (probably caused by improper tapping). The raised metal was removed with a bearing scraper to reduce leakage between the turbine and the seal plate.

Rubber alcohol seals often leaked after calibration. It was found that if these seals were replaced with unused German seals before calibration, the new seals would withstand calibration without leaking. This indicated that the seals had lost their resiliency after the prolonged storage in a flexed position.

The studs on the oxygen cover plate were made of steel in most turbopumps, but on a few, the material was aluminum. It was difficult to obtain a good seal between the cover and the pump casing on turbopumps with the aluminum studs, since the studs could not be torqued down tightly without breaking.

A number of turbines leaked air between the nozzles and manifold and/or between the nozzles and turbine cover. In some cases, gaskets were missing from these places. Two such turbines were repaired, but in the process, so many threads were stripped in the turbine cover that it was decided not to use similar turbines for the rest of the program.

The lox-pump cheek pieces were sometimes temporarily or permanently distorted when the holding screws were torqued too tightly. This resulted in leakage between the cheek piece and the pump.

f. Turbopump disassembly procedure: A prick punch was used in all cases where alignment marks were needed, except that seal covers were aligned by scribing. Care was taken to insure that punch or scribe marks were not made in or adjacent to any area that contacted any other part of the turbopump. Also, personnel were careful not to mar any bearing or seating surface. In general, the procedure noted below was followed.

The steam ring was removed after first removing the insulating covers from the connections. Gaskets between the ring and the turbine were not removed.

The two cheek pieces between the lox pump and the turbine were marked at adjacent spots on their outer periphery. These marks were made lightly and as far as possible from the juncture of the two cheek pieces, to keep from raising an area on the seating surface. The lox pump was then lifted from the assembly after first removing the four holding nuts. Then, before either shaft was turned, both sides of the flexible coupling were marked at points adjacent to the marks on the cheek piece. This "round-about" method of aligning the flexible coupling pieces was necessary, since the pieces were not accessible before the lox pump was removed.

Four spacers between the turbine and the lox pump were marked to provide for correct positioning when replaced.

The flexible coupling holding nut on the turbine side was removed, and the shaft and flexible coupling were marked. The flexible coupling was removed, and a scribe mark made to align the seal cover. To avoid later damage, the seal cover and seal were removed at this time.

The turbine cover holding nuts and the two alignment pins were removed, and the turbine cover lifted off. During removal, the cover would often strike against the shaft. Therefore, it was decided to remove the turbine seal before this operation.

The turbine wheel was marked, and the reversing bucket segments were loosened from their alignment pins by prying upward against the ends of the segments (not between the segments and the case). A bearing puller was used to remove the turbine wheel.

The four turbine-casing holding nuts were removed and the turbine case lifted free from the alcohol pump. Care was taken not to strike the case against the shaft, since this would damage the turbine seal. The four spacers were marked to insure correct positioning when replaced. The turbine seal bushing was removed from the shaft and the turbine seal was removed from the turbine case after first marking the cover alignment with a scribe.

The overspeed case and holding nut were removed, and the overspeed disk was removed from the shaft. When it was necessary to pry the overspeed disk off, it was done carefully, since bending of the disc edges could result in a changing of the trip setting. The grease seal adjacent to the overspeed was removed by prying on the sides (not bottom) of the seal.

The alcohol leak line and the alcohol pump cover were removed. The cover could not be tilted while being removed, since this would jam the bearings. Care was taken to avoid stretching the sealing ring gasket. The bearing was easily removed from the cover with finger pressure if care was taken not to tilt the bearing.

Next the bearing plate on the turbine side of the alcohol pump was removed. The alcohol-impeller holding nut was removed, and the shaft and impeller were marked. A nut was screwed on the end of the shaft, and the shaft was removed by tapping lightly on the nut with a plastic mallet.

Alcohol seals were removed by "driving-out" with a 3/8-inch round drift pin. Care was taken not to let the drift slip, since a small dent in the metal seating surface could cause leakage. Some turbines had a snap ring and seal holder on the turbine side of the pump. These had to be removed before the smaller seal could be driven out.

The nut on the lox pump flexible coupling piece was removed; the coupling and shaft were marked and coupling removed.

The cheek piece on the lox pump was removed, care being taken not to break the gasket or allow the seals to strike the shaft. The adjacent lox pump bearing and thrust piece were then removed. Seal covers, seals, and spacers were removed from the cheek piece after first marking the cover alignment with a scribe mark. Patience was required in removing these units, since even the slightest tilting of the spacers would cause jamming.

The lox cover holding nuts were removed and the cover forced off by screwing two studs into the holes provided in the cover. Gasket material was scraped from the lox cover and lox pump. The impeller and shaft were removed as a subassembly and no further disassembly made.

g. Turbopump assembly procedure: Most washers on the turbopump were curved lock washers although they appeared at first glance to be plain flat washers. Therefore, if any were lost or broken, they were replaced with like washers taken from another turbopump.

In general, the following assembly procedures were used after the parts were cleaned and, where necessary, degreased.

The lox impeller and shaft were installed in the lox pump casing, and the lox pump bearing and thrust piece were placed. Seals and spacers were replaced in the cheek piece, making sure that the segment joints were staggered. The seal plate was lined up with the scribe mark and screwed into place; the cheek piece gasket was replaced. The lox pump bearing was rotated so that its pin would line up with the slot in the seal plate, and the cheek piece was installed and tightened. Overtightening was avoided to prevent buckling of the cheek piece.

Lox pump seals were centered, and the flexible coupling was lined up and replaced. If the coupling did not slip easily into place, it was removed and the seals again centered (any attempt to force the coupling would result in seal damage). When the coupling was in place, the center nut was replaced and locked by driving some of the outer skirt of the nut into the two slots provided for that purpose.

Gasket areas on the lox pump cover and lox pump casing were covered with a water-glass and feldspar powder mixture, the gasket put in place, and the lox cover replaced and tightened. No pressure test was made for at least 24 hours to insure that the gasket-seal mixture was dry.

Alcohol pump seals were driven into place with a hardwood block. The seal holder and snap ring were installed (on turbines so equipped) before the large seal was installed.

Both alcohol pump bearings were cleaned and repacked with light grease. The alcohol pump shaft was put in place and the bearing on the turbine side of the pump was installed. The bearing plate was put on and tightened evenly.

The alcohol pump impeller was installed on the alcohol pump shaft and the nut was installed and tightened. To lock the nut in place, the locking washer was bent upward.

The alcohol sealing ring gasket was put in place on the pump cover. If the ring had stretched, it was shortened and the free ends cut at an angle and joined by rubber cement.

A special conical assembly tool was placed over the overspeed end of the alcohol shaft to protect the alcohol pump seals; the alcohol pump cover was lined up and pushed partly into place. Before the cover was put completely on, a visual check was made to insure that the inside seal spring had not slipped off the seal. The cover was then pushed into place and bolted down, the overspeed assembly tool was removed, and the bearing, grease seal, overspeed disk and overspeed nut were put in place. The overspeed case was installed and the four holding nuts tightened down evenly to insure proper alignment of the case; the leak line was then replaced.

The turbine seal bushing was put on the shaft with the groove toward the alcohol pump. Four spacers were installed on the alcohol pump and lined up with the punch marks. The seal was installed in the turbine case and the seal cover aligned and tightened. The turbine case was then installed on the alcohol pump, making certain that the seal did not strike the shaft and that the seal was centered so that it would slip easily over the seal bushing. Any attempt to force the case into position would result in damage to the seal. After it was certain that the spacers were fitted correctly into the alcohol pump and the turbine case, sealing washers were slipped over the four alcohol pump studs and the nuts were tightened. These nuts were locked in place by driving a part of the nut skirt into a hole provided for that purpose.

The turbine wheel and reversing segments were aligned and lowered into place, and the segments tightened. Two alignment pins on the outer circumference of the turbine were placed in position, the turbine gasket replaced and the turbine cover positioned and tightened. The seal was put in place and the seal cover aligned and tightened. The flexible coupling piece was aligned, slipped into place and tightened with the center holding nut. If the coupling could not slip easily into place, it was removed and the seal re-centered (any attempt to force the coupling into place would result in seal damage). The nut was locked by driving some of the skirt of the nut into the spaces provided for that purpose. Both parts of the flexible coupling were rotated to the exact position they occupied when the turbine was disassembled (as determined by the punch marks on the flexible coupling pieces and the cheek pieces). Four spacers were installed on the turbine studs and aligned with the punch marks. The lox pump was then put in place, tightened and the spacers examined to make certain they were seating correctly on the turbine and the lox pump.

The steam ring was replaced and tightened, and the insulating covers installed.

The turbine was then rotated to determine if it was turning freely. If it was binding, the center cap on the lox cover was removed and the lox shaft tapped (using a plastic mallet and drift pin) until the lox pump shaft was heard to seat against the turbine shaft. The center cap was then replaced and tightened.

h. Testing specifications: The lox pump was pressurized to 28.4 psi with the air source cut off; the pump failed test if the pressure fell below 9.9 psi in 120 seconds. Original specifications allowed this drop in 60 seconds, but this was changed later in the program. With 28.4 psi pressure in the pump, leakage was not allowed between the turbine and cover nor at any fittings.

The alcohol pump was pressurized to 25.5 psi; no leakage was allowed. All joints and fittings and the leak line were checked with soap solution.

The turbine was pressurized to 22.7 psi. With the air source cut off, the turbine failed test if the pressure fell below 7.1 psi in 60 seconds. With 22.7 psi pressure in the turbine, no leakage was allowed at any place except the seals.

i. Overspeed Assembly: A test determined the speed at which the overspeed trip ring began to move out as compared to the speed at which the overspeed trip ring had moved completely out. It was found that once the trip ring had begun to move out, it would probably move completely out at that same speed and would definitely be completely out at 200 additional rpm's.

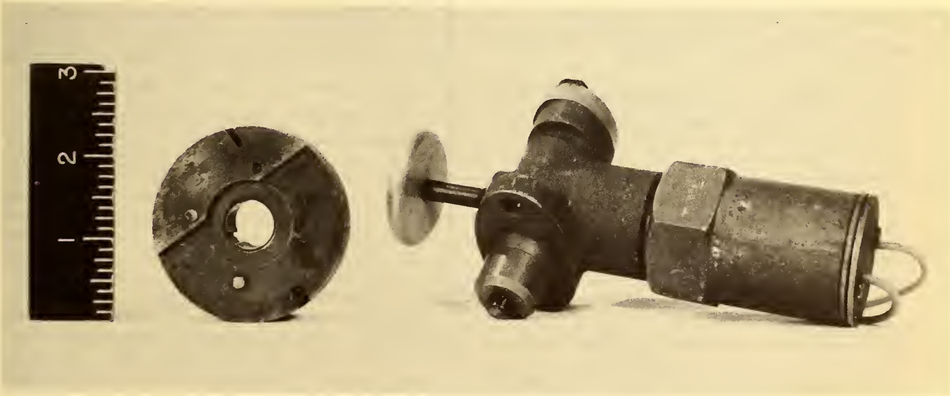


Fig. 32 V-2 Turbopump Overspeed Trip

Some overspeed cocking levers could be placed, by accident or otherwise, in such a position that electrical contact would not be made. However, a jar or vibration would cause the contact to be made. All assemblies tested, would function properly if the cocking lever was pulled completely out to the stop.

Each complete overspeed assembly was installed on a test rig and the speed at which the trip was actuated was maintained between 4800 and 5200 rpm. During the latter part of the program, the tripping range allowed was changed to between 5000 and 5200 rpm. The trip point could be adjusted by disassembling the overspeed disk and changing the number of shims under the spring.

A WSPG test report sheet for the turbopump is shown in Figure 33.

A.2.7 Alcohol Main Valve

References: A-4 Manual, p. 116, 121 and 133; Backfire, Vol. II, p. 43, 45, 101 and 104.

Many porous cases were found during tests of the alcohol main valve. This may have been a manufacturing defect, but could have been caused by aging or corrosion. Disassembly of such valves showed numerous pits on the inner surface of the case.

TEST REPORT

TURBO PUMP

No. of Pump:

Built into Rocket No.:

1. Visual Examination

(a) Were the intakes and outlets of turbine, oxygen pump and alcohol pump closed?

(b) Was there any visible damage? If so, where?

2. Disassembly

(a) Was the turbo pump disassembled? If so, how far?

(b) Remarks

3. Pressure Test

(a) Turbine:

(1) Test pressure (2) Pressure decrease to

in seconds. (3) Leaks? Where?

(b) Oxygen Pump:

(1) Test pressure (2) How often was test repeated?

(3) Pressure decreased to atm. in seconds.

(c) Alcohol Pump:

(1) Test pressure (2) Leaks at the leak line?

(3) Pressure decrease to atm. in seconds.

(4) Leaks? Where?

-2-

4. Cleaning

(a) Oxygen Pump:

(1) Cleaned with air

(2) Cleaned with solvent

(3) Dried

(b) Alcohol Pump:

(1) Cleaned with air

(2) Cleaned with solvent

(3) Dried and oiled

(c) Turbine:

(1) Cleaned with air

Remarks

5. Overspeed Cut-off

(a) Release tested

(b) Electrical switch tested

6. Could the turbo pump be easily rotated by hand?

7. Final Operation

All lines and fittings closed dust-tight

Tested by: Date:

Fig. 33 Turbopump Test Report Form

Although many and varied defects were noted, there was no instance in which the valve failed to operate. There were, however, many instances of very rough strokes. Disassembly of these valves showed a scoring on the center cylinder where the stem-nut moved. In some instances, this scoring was quite severe (pieces of aluminum had been rubbed off the cylinder). This was probably caused by manufacturing errors, either in tolerances or in alignment. To make certain that sticky "U" cups were not causing rough strokes, two valves with rough strokes were disassembled and a graphite base lubricant ("Aquadag") was applied to the surfaces that would be in contact with the "U" cups. When reassembled, the valves continued to operate with rough strokes. A rough stroke in this valve was serious for two reasons. First, it indicated that a rubbing between two metal surfaces existed which might result in a complete seizure at a later time. Second, it might cause a missile failure at takeoff (explained in the oxygen main valve section of this report). A minor design change to increase the clearance between the center cylinder and the stem nut, to provide no contact between the two units, would probably have eliminated the rough stroke. This would have necessitated inserting a thrust washer on top of the spring and increasing the inside diameter of the stem.

The vertical air inlet fitting elongated badly with moderate torque. Although no failures occurred, there was considerable necking; replacement parts of steel were utilized. If it was thought necessary to use aluminum for the new fittings, smaller diameter elongated holes placed vertically so that the metal cross-sectional area through the holes was greater, would have been utilized. Also, a heavier-walled fitting could probably have been adopted.

At one time, control air leakage was consistently appearing at the large nut on top of the valve, indicating that the gasket between the cylinder and case was not sealing correctly. It was noted that the installation and tightening of the return line rotated the cylinder to the extent allowed by the Woodruff key, this loosened the nut by that amount. Tightening the large valve nut after the return line was tightened corrected the difficulty.

There was one instance of leakage past the main seat of the valve. This was caused by a flat spot on the knife-edge of the burner. A second valve was installed and no leakage was detected past the seat. Although no hardness tests were made, it was assumed that the rubber composition was softer on the second valve than it was on the first.

At one time, these valves included a switch which operated when the valve went to the preliminary stage position. This switch was used as an interlock to prevent main stage operation if the valve had not operated. It is not known why this switch was later omitted, but it seems that an operator could be expected to wait for a preliminary flame before giving main stage, in which case the switch would not be necessary.

Figure 49 on Page 133 of the A-4 Manual notes that this is a "pressure switch for control of the prestage motion." Actually, this was not a pressure switch in domestic terminology, but a mechanical switch operated by a push rod which rode on the valve stem.

It was possible to adjust the preliminary stroke by turning the valve disk and locking nut on the stem.

The Germans suggested the removal of the alcohol return line, and the capping of the top of the valve. They considered that the original reasons for this design, that is, the reduction of: (1) water-hammer and (2) the possibility of burner explosion, were not sufficient to warrant continued use of the system. Tests at WSPG did not indicate the severity of the supposed water-hammer if the valve were used with the bypass blocked. Some tests, however, showed that the valve would lack 1/8-inch of closing completely under control air pressure with the by-pass line in position. With the by-pass line blocked off, the condition would be changed considerably, but effective pressure areas indicated that with 500 psi control pressure, 220 psi alcohol pressure would begin to open the seat if there were no burner pressure. This showed that there would be no continuous complete closure of the valve, although the restriction to flow caused by the valve might be enough to cause a water-hammer effect or cause excessive pump-outlet pressure. Possibilities of a burner explosion would be increased by the blocking of the return line. All air in the burner would be entrapped during alcohol filling. During the rest of the firing preparation, this air would have time to mix with vapors given off by the alcohol, with the resultant possibility of an explosion in the combustion chamber when the alcohol valve was opened. If this happened, there would have been a good possibility of the flame propagating back through the nozzles and causing an explosion in the jacket.

A.2.8 Alcohol Preliminary Valve

References: A-4 Manual, p. 56 and 123; Backfire, Vol. II, p. 34, 41, 42, 104 and 105.

The primary function of this valve was never entirely clear, although there are a number of possible purposes.

a. The Germans pressurized the alcohol tank after burnout to prevent the collapse of the tank upon its re-entry into the atmosphere. There would have been some loss of air through the Z.K. nozzles if there had been no preliminary valve.

b. If control air was last prior to launching, the preliminary valve would have prevented the dumping of tank alcohol, although the alcohol in the piping would have been dumped.

c. In the event of a misfire in which the Z.K. nozzles had been melted, the preliminary valve would prevent prolonged burning caused by alcohol being supplied through the Z.K. nozzles.

d. Possibly this valve was originally designed into the system to confine the alcohol to the tank until just before firing thus preventing the freezing of alcohol in the tube that runs through the lox tank.

The test of this valve was extremely dangerous to personnel not thoroughly acquainted with its operation. In at least one instance (not at WSPG) a test man was severely injured when his hand was caught between the valve body and the valve cone.

Travel of the indicating switch was adjusted by adding shims beneath the push rod. Too many shims, however, would cause damage to the switch. The switch was held in place by a cover nut with a rectangular rubber grommet between the cover and the switch. This arrangement was generally unsatisfactory for, over a period of time, the grommet would flow around the switch causing it to move away from the push rod far enough, in some cases, to become inoperative. In other instances, the switch would be floating within the grommet and would operate only part of the time, or would operate only after a short time lag. In all instances in which switch trouble occurred after the tanks were put into the midsection, a pressure switch was installed in the valve pressurizing control line to perform, as closely as possible, the same function as did the valve switch. Later in the program, failures were practically eliminated by using good grommets from valves that had never been completely assembled and assembling the valves only a short time before they were to be used. It was also determined that a small torque on the switch cover nut would effectively seal against alcohol leakage, and would lessen the tendency for the grommet to flow. Approximately 50 percent of the switches were cracked or broken. Possibly many of these were damaged by excessive tightening of the switch cover. There were other cases of inoperative switches caused by corrosion and contact misalignment. Experience at WSPG indicated that heavier duty switches were needed for this application.

The valves were assembled in Germany with solid conductor switch leads. These were changed to stranded wire after the first 20 to 25 firings at WSPG. The aluminum tubes were replaced with copper tubes for ease in installing the new wire.

In the initial assembly of the valve (during manufacture) a small hole was drilled through the top locking nut and into the cylinder to take the spring locking clip. In one instance, the hole was drilled completely through the cylinder. This defect was not noticed until alcohol was observed leaking from the midsection.

In many instances, the 10 mm threads in the cylinder stripped out while tightening the adapters. Stronger 12 mm threads could have been used without difficulty.

The gasket between the "U" cup holder and the cylinder was fibre in most instances. The fibre units caused considerable trouble and many had to be replaced. However, no trouble was encountered in the few valves that had aluminum instead of fibre gaskets.

During one valve bench-test, a threaded nut on the bottom of the valve stem pulled away from the valve cone. To determine the average strength of these connections, three valves were tested by securing the covers to the bodies and applying control pressure. In all three cases, 2000 psi control pressure was insufficient to break the stems loose from the cones. It was never determined why the one stem nut was so weak. The valve stems on about 30 percent of the valves were pitted and/or corroded.

The plug in the control pressure passage sometimes leaked control air. This had to be checked when the case and cone were removed.

In almost every valve, the "U" cups had taken a permanent set and would not seal control air. Spare German "U" cups were available at WSPG. These were invariably good and would seal, except when the cylinder or push rod was defective.

A throttle valve in the control line of this valve provided a means for the slow closing of the valve. The only reason advanced for this slow closing was that it would protect the rubber seat from being slammed against the tank. With 510 psi control pressure, an average of 7.0 seconds elapsed between the de-energization of the control valve and the complete closure of the valve. The valve stem did not begin to move to the closed position until 1.8 seconds before the complete closure of the valve. This was determined by a bench test; actual flight conditions would be somewhat different.

A.2.9 Oxygen Fill Valve

References: A-4 Manual, p. 57 and 125; Backfire, Vol. II, p. 53, 55 and 103.

Twenty to thirty percent of the valves on hand at WSPG had cracks between the bolt bosses and the cases. This was caused by excessive tightening of the mounting bolts, coupled with the design weakness of the casting.

Considerable trouble was experienced with leakage past the seats of these valves. Although re-turning of seats and lapping with a lapping compound was tried, it was found that lapping the two surfaces together with plain lubricating oil was most effective. Even when following this procedure, some valves would leak lox after filling. This could sometimes be remedied (at the time) by tapping the seat very lightly with a wooden hammer handle, or equivalent. If this did not stop the leakage, the cap was put on and tightened, leakage was then confined to the valve. This was satisfactory, except that it was very difficult to remove the cap for lox topping. Some caps stuck so tightly that it was believed the piping might be broken in the process of removing the cap. On later missiles, a 5/16-inch OD section of copper tubing was run from a fitting installed in the cap to the lox vent line. This line carried away the leakage, makin it no longer necessary to tighten the cap excessively.

There were a few instances of porous cases.

A.2.10 Switch Battery (Pilot Valves)

References: A-4 Manual, p. 141 and 149; Backfire, Vol. II, p. 51, 52, 54, 56, 110 and 111.

Paragraphs 58 and 59 in Backfire, Volume II mention that the cast-body-type valve is obsolete. This, however, was the type used at WSPG.

The switch battery was one of the three most troublesome valves. The following faults, in order of frequency, were found: (1) leakage past external aluminum washers, (2) leakage past outside rubber ring washers, (3) leakage at servo bleed holes, (4) leakage at main bleed holes, (5) slow operation, (6) no operation, (7) leakage by electrical pins, and (8) low insulation resistance. At least one instance of each of the above faults could be found by testing a half dozen switch batteries; faults (1) and (2) could be found many times. Some of the leaks could be stopped by tightening, however, only about one-third to one-half of the switch batteries tested could pass tests. No attempt was made to overhaul the defective valves since our supply was adequate. There were no instances of leakage through the case.

During the first part of the program, a number of switch batteries had to be changed at the launching site due to slow operation. This was reduced during the latter part of the program by passing (on the basis of bench tests) only those valves that were very rapid in their operation. A slight increase in operating time would not necessitate the changing of the valve.

Often leakage would occur after a missile had been loaded with lox, but these leaks were almost always stopped by tightening.

Quick-disconnect terminals were soldered to the electrical pins on later missiles, since there was concern that the original plugs might not be making good contact.

In one instance, it was believed that moisture collecting around the electrical pins caused a misfire when the resistance across the pins became so low, a fuse was blown in the firing desk.

A.2.11 Burner Drain Valve

References: A-4 Manual, p. 141; Backfire, Vol. II, p. 55.

Most of the burner drain valves used at WSPG were American-made. About 20 percent of these were defective in that the hand wheel could be turned completely off. When this happened, reassembly was a major job. No valves showed any leakage.

A.2.12 Ram Charger Valve

References: A-4 Manual, p. 56 and Backfire, Vol. II, p. 37, 103 and 104.

The tube from this valve to atmosphere was, in most cases, run through the warhead. On some missiles at WSPG the tube was run through a door in the control compartment.

Approximately 15 percent of valves tested leaked control air. In most of these defective valves, the leak was past the metal-to-metal top seal. Five valves manufactured in the United States were tested; three leaked control air.

A.2.13 Alcohol Tank Drain Valve

References: A-4 Manual, p. 57; Backfire, Vol. II, p. 43, 44, 106 and 107.

Trouble was not experienced with this valve except for leakage (in a few instances) past the aluminum washer on the spring-holding eye bolt.

A.2.14 A-3 Check Valve

References: A-4 Manual, p. 114 and 128; Backfire, Vol. II, p. 25 and 33.

This valve prevented gas from being lost through the burner before and after burning, as well as preventing liquid oxygen from filling the heat-exchanger coils before steam was available. Considerable trouble was experienced with leakage past the gaskets. A number of valves were found with rusty springs and/or rusty seats.

A.2.15 Oxygen Vent Valve

References: A-4 Manual, p. 57 and 129; Backfire, Vol. II, p. 43, 47, 102 and 103.

Practically all valves tested, leaked at the steel control chamber cap. Except in isolated instances, this leakage could be stopped by additional tightening of the cap.

In most instances the safety feature of the valve was out of adjustment. If the spring compression was not adjusted carefully, the spring would be subjected to a torque which would cause the setting to change after the valve had been operated a few times. A special wrench was used to keep the spring from turning when the adjusting nut was being set.

An estimated five percent of the valves tested had one or more holes or pores through the case.

A few valves had leakage past the plastic piston, but in practically every instance this was due to nicks or pits in the seat of the case.

Many of the valves had a coating on the leather facings of the large piston that looked and felt somewhat like soft soap. This coating seemed to give a better seal against leakage, but it was removed as a safety precaution. Many of the valves leaked more than the allowable amount (2.54 cfm) past the leather seats. This was due to the pitted and scarred condition of the leathers.

The Germans considered that the relief feature of this valve could not be depended upon for personnel safety. According to one source, the Germans once actually shot holes in the lox tank to relieve pressure after control air was lost. During a test in Germany, the automatic cutoff did not function during lox tank pressurizing and the lox tank blew up because the vent valve could not pass enough gas to keep the pressure low. A test was made at WSPG to determine the amount of pressure rise that could be expected with a higher input volume. This was of course a bench test and no tank was used. With 2500 psi applied through 1/4-inch OD thin-wall copper tubing, a lox vent valve that had passed all regular bench-tests held a chamber pressure of 54 psi. This would be sufficient to blow up a lox tank. During this test the valve box had a restriction in the lox tank pressurizing line which reduced the flow. However, it is possible that the valve box in the incident referred to by the Germans did not have this restriction. The specification for a regular bench test was that flow resulting from a pressure of 355 psi supplied through a 0.8 mm orifice, should give a valve chamber pressure of from 28.4 to 31.2 psi. It is not known how this volume was arrived at; possibly it is the calculated rate of lox vapor given off by lox boiling.

The normally-open valve in the valve box that controlled the vent valve was designed for quick bleeding; the vent valve would slam shut and therefore seat better.

Tests were run to determine the effect of heating on the plastic control pressure pistons. It was found that temperatures as low as 65°C might render the valve permanently inoperative.

The following information was obtained from German manufacturing directions: (1) spring and lock rings were zinc coated, (2) small pores were allowed in the case, (3) guide ribs and seats were machined in one setup, (4) rings were made of leather from the underside of the animal and were degreased with trichloroethylene, (5) rings were cemented into the piston by applying the glue, installing the leather and applying pressure by putting the piston in the corresponding casing and then loading the piston, (6) outside diameter of the leather rings could not exceed the outside diameter of the piston and (7) oil or grease were not used during the manufacture of any part of the valve.

American-made vent valves were manufactured to German specifications and were used on many of the later missiles. Many of the valves leaked control pressure past the steel cap. In the later shipments, this was corrected by using a copper washer between the cap and case. There was no instance of a porous case on any of the valves. Leakage past the leather seats was very small. The plastic piston would withstand about 10°C more than the piston in the German valve.

On a number of valves, the large piston was picking up metal where it rubbed against the case. It was later found that the clearance between pistons and cases was between zero and 0.006 inch, as compared to 0.009 inch or more on the German valves. All American-made valves were therefore disassembled and the pistons turned down to give a clearance of from 0.011 inch to 0.012 inch before use. This eliminated the trouble completely. In examining telemetry records, it was noticed that lox tank pressure would often reach a peak then drop down 5 to 10 pounds before starting to rise again. Since this condition was not evident after the valve clearance was increased, it was considered possible that the valves were binding slightly if the clearance was small. These results could not be duplicated on the ground, even by cooling the valve with liquid oxygen boil-off.

A.2.16 Oxygen Main Valve

References: A-4 Manual, p. 121 and 131 and Backfire, Vol. II, p. 47 and 48.

Figure 34 is a cutaway view of the main oxygen valve.

The electrical connection leaked control air in most valves and had to be tightened. In some valves, the plug had to be removed and the gasket replaced. A few valves leaked air past the steel gasket located below the metal-to-metal seat.

During the latter part of the program, valves were used that had leakage past the metal-to-metal seal (twice the amount allowed on the first valves fired). Since this leakage seemed to get worse with time, it was suspected that corrosion was pitting the surfaces. Although several methods were used in an attempt to decrease this leakage, none were successful. The methods included: (1) grinding and lapping the surfaces with various compounds and by various methods, (2) making new seating disks and (3) copper-plating the seating surface on the piston.

The item that caused the most trouble of all propulsion components was the double lip seal in this valve. If this seal were too loose, lox would leak past it and vaporize in the control chamber. If the vaporization was so rapid that it could not be relieved through the switch battery, the resultant pressure would start to close the valve. As the pressure in the control chamber was relieved through the switch battery, the valve would start to move to the full open position which would admit more lox to the control chamber and start the cycle again.

If the seal were too tight, the stroke would be rough, which could cause a missile to topple at takeoff. According to the Germans this happened at times in Germany. The theory behind this is as follows: a smooth operating alcohol main valve combined with a sticky oxygen valve may result in a condition in which the oxygen valve sticks at the position where the thrust just overcomes the weight of the missile; the main alcohol valve would continue to open, and as more alcohol entered the burner, the thrust was decreased and the missile would settle back.

In the latter part of 1948, it was found that the double lip seal was loosening when the valve was cooled with liquid oxygen. Tests at Fort Bliss and WSPG showed that control air leakage increased greatly; lox vapors from the switch battery were observed. It was found that tightening of the seal nut when the valve was cold would decrease the leakage. However, if the seal nut was tightened too much, a rough stroke would sometimes result. Additional cold tests at Fort Bliss indicated that it was the temperature difference between the seal and the cylinder that was causing the leakage. Cold tests were run with a calrod unit wrapped around the bottom of the valve; this reduced the leakage considerably. The calrod power was supplied by a variac which was adjusted to insure that the calrod would not become uncomfortably hot to the touch. Immediately after the double lip seal trouble was discovered, missiles were supplied with a 25-ton valve on the bottom of the main valve to aid in venting the control chamber. The vent lines on the 25-ton valve and on the switch battery were run to the side of the missile. Also, the calrod was utilized and control air leakage was monitored until access ports were closed to make sure the seal was not loosening to a dangerous degree.

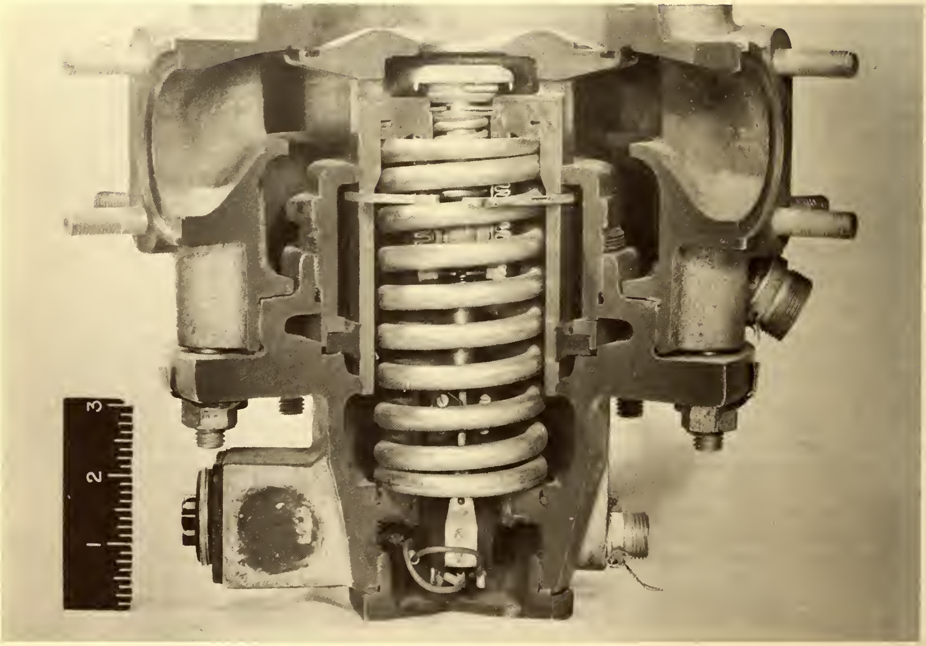


Fig. 34 Cutaway View, Main Oxygen Valve

Meanwhile, the General Electric Research Laboratory at Schenectady was developing new type seals, since it was believed that the trouble could be attributed to the old seals having lost much of their elasticity. Several development seals were tested at Fort Bliss and sent to WSPG. These seals were slightly smaller in diameter, and considerable stickiness was experienced until the seals and cylinders were coated with "Aquadag," a collodial graphite compound. It was found that the amount of torque used on the seal nut did not effect the leakage appreciably. The leakage with the new seals was quite low, even when the calrod was not used. These new seals were used on the last few missiles; on the last four missiles, the calrod was not turned on.

A.2.17 Steam Plant

References: A-4 Manual, p. 17, 78 through 91, 121, 127, 128, 135, 142 through 153 and 222; Backfire, Vol. II, p. 34 through 40, 53, 57, 59 through 72, 84, 104 through 111 and 116 through 119.

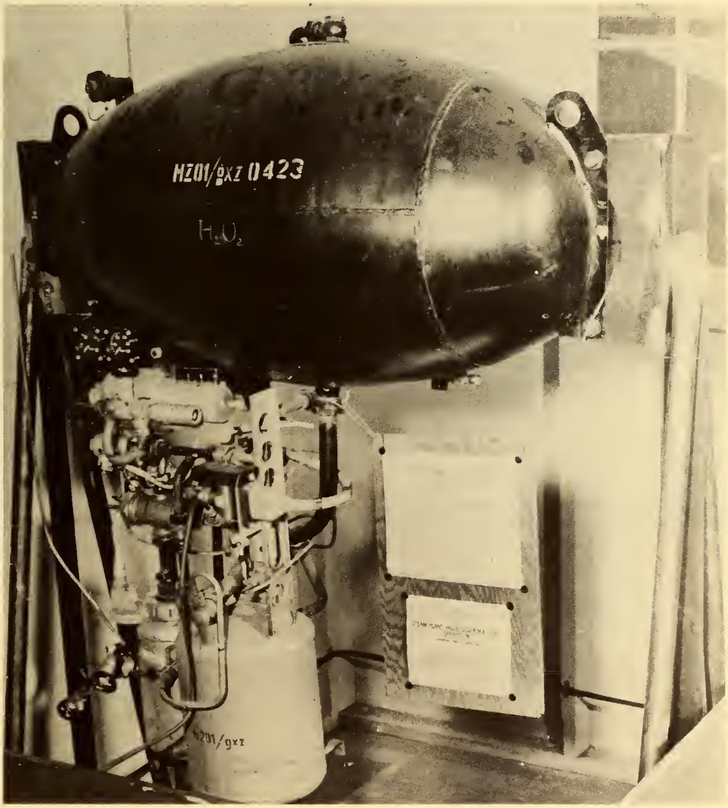


Fig. 35 V-2 Steam-generating Plant

a. Reducers

At least two reducers stuck at the launching site after lox was filled. It is believed this was caused by moisture freezing between the shaft and the brass adapter. In both cases, the reducer became operative when the pressure was dropped somewhere below 300 psi. On later missiles, the heater was turned on at the start of lox filling. The heater remained on until takeoff, unless the firing was delayed, in which case the heater was turned off if the reducer got uncomfortably hot to the touch.

A half dozen or more reducers were changed at the launching site. The reason for this was always that the differential pressure (difference in pressure between small bleeder valve open and small bleeder valve closed) was too great. A differential pressure greater than 28 psi indicated that the reducer was getting dangerously sticky or the seat was being pitted.

During the first part of the program, the reducers were set immediately before leaving the missile. On later missiles, the reducers were set before liquid oxygen was filled after first having the heater on for about 10 minutes. The inlet pressure was kept as near 2500 psi as practicable, although some reducers were set with inlet pressures as low as 2100 psi. Reduced pressure was monitored at the missile until the access hatches were replaced and on later missiles was monitored in the blockhouse until launching. It was found from bench tests that the static pressure and the dynamic (small bleeder valve open) pressure were erratic when the reducer was cooled, but the full flow pressure remained the same. Therefore, the reducer was set before lox filling.

A very few of the reducers fluctuated badly during the flow test. This indicated stickiness between the shaft and the brass adapter in the open position. About a third of the reducers had too great a differential pressure during the initial steam plant test and were replaced. Some reducers stuck partly open or closed during the initial flow test.

All of the reducers disassembled had a thin coating of grease on the inside. When this coating was removed, the differential pressure increased. Also, the difference between dynamic pressure and full flow pressure increased.

To minimize a permanent set of the spring, the adjusting screw was removed when pressure was not required. This was merely precautionary, since experience on the calibration stand indicated that practically no permanent set occurred over a period of two to three months. Many of the adjusting screws did not fit well into the spring case and some seized.

The spring cover was vented on all reducers. Some reducers had a hole drilled in the end and others had a small check valve on the end of the adjusting screw. When it was necessary to change damaged adjusting screws, care was taken not to put a blank adjusting screw into a case that had no relief hole. There were instances of leakage past the diaphragm as evidenced by leakage out of the relief hole or relief check valve.

When a reducer stuck closed, it would cause an over pressure when it became free which would actuate the relief valve. The relief valves had to be adjusted before they were operated, since they had been assembled so long that the rubber seat had flowed around the knife edge, resulting in a much higher initial relief pressure.

b. Gages

The N4R contact on the 0-60 kg per cm^2 gage was not consistent in its operation. After the first 20 or 25 missiles, a line was tapped into this gage line and an American built pressure switch was installed.

The glass covers on both gages were replaced with plastic covers which had 1/8-inch diameter holes drilled through. This was done because the bourdon tubes would sometimes fail and the pressure would shatter the glass front.

c. High Pressure Hand Valve

This valve would often stick open. The check-valve part of the valve gave no trouble. Pressure differential across the valve varied from zero to eight atmospheres.

d. Peroxide and Permanganate Bleed Valves

There was no known instance of any malfunction of these valves.

e. Peroxide and Permanganate Drain Valves

These valves often leaked pressure at the metal-to-metal juncture of the two halves of the case. The external drain coupling would sometimes leave the seat tilted to one side, preventing the valve from sealing against liquid.

f. Steam Generator Check Valve

According to one of the German engineers, the check valve was installed to avoid an explosion in the steam generator (which might flash back into the peroxide tank) if the permanganate line should become clogged and then cleared. During the latter part of World War II, the Germans made tests to determine if the valve could be eliminated, however, no conclusive results were obtained.

g. Peroxide and Permanganate Check Valves

There were two different spring-types in these valves. One valve unit had a steel spring. In the other, the spring was machined out of the same piece of aluminum or brass as was the seat, and was still attached to the seat. The steel spring valves worked well, but many of the brass and aluminum springs had taken a permanent set in the compressed position and were worthless.

h. Twenty-Five Ton Valve

Some of these valves leaked control air and were replaced. A few were rejected because of rough strokes. Tests run on three valves showed that the valve would begin to open at about 25 psi if there were no tank pressure, and that once open would remain open against 600 psi tank pressure even if the control pressure dropped to 50 psi.

i. P. E. 4 Valve

Some of these valves would not pick up at the required voltage (18 volts). Pneumatically, the valves were very good, and only an occasional defect was noted. One valve was energized with 30 volts for 7 hours without burning out; the outside of the coil reached a temperature of 120°C. Terminal covers were not securely fastened and would often be blown off. In one instance (in the test room) the cover shorted across the terminals when the holding strap kept the cover from being blown clear. After this, all such covers on the missile were attached down with friction tape as an extra precaution.

j. Eight Ton Valve

About 30 percent of these valves leaked past the seat and were rejected. One of the valve coils was energized with 30 volts until it burned out. It began smoking in 40 minutes and burned out about 2 hours later; the case reached a temperature of 255°C. At normal operating pressure, the valve would open with about 13 volts. Flow through this valve was regulated by an orifice in the peroxide inlet line.

k. Main Stage (P. E. 1. 0) Valve

This valve was one of the three most troublesome valves. Approximately a half of the units were defective and had to be repaired or discarded. The plastic pilot scored and pitted easily, causing leakage at the bleed holes, often rendering the valve inoperative.

Many of the "U" Cups had taken a permanent set and were replaced with spare cups. The rubber seats were often pitted and some came out completely. With normal operating pressure, this valve would open with about 10 volts. Two of the valve coils were energized with 30 volts until they burned out. Both began smoking after about 45 minutes, and burned out immediately after. Outside case temperatures were 172 and 120°C.

A.2.18 Main Tanks (Alcohol and Oxygen)

References: A-4 Manual, p. 51 and 221; Backfire, Vol. II, p. 24, 26, 93 and 111.

On some tanks, the brackets were welded on, not riveted. These were not used at WSPG until the brackets were riveted on. Leaks at rivets were repaired by re-riveting.

The side plates used to steady the tanks in the midsection were slotted to allow for tank expansion and contraction.

Most lox tanks had holes or weak spots that had to be welded.

An attempt was made to pressurize an alcohol tank to rupture. However, the skin pulled away from the stiffening rings, leaving holes in the skin which leaked so much air that the pressure could not be held. Maximum pressure reached was 41.5 psi.

An oxygen tank was pressurized to rupture; it ruptured across the top end at 52.6 psi with explosive violence.

A.3 TEST INSTRUCTIONS

The following are test instructions for the propulsion components. Original instructions gave test pressures in kilograms per square centimeter. Valve travel is still listed in Millimeters since almost all valves used were original German units. Leakage in "bubbles per second" refers to the leakage from a 1/4-inch OD thin-wall copper tubing immersed in about three inches of water (it is admittedly a very crude measurement).

A.3.1 Carbon Vanes

a. Examine x-rays and compare faults and classification with inspection sheet. The vane must be Class A or Class B.

b. Examine vane for broken tips and other obvious defects. Discard any vane with red stripe painted on the surface.

c. Examine side strips and replace broken units.

d. Using a wire brush, clean rust from the backing plate.

e. Check the clearance between the vane and the backing plate. This clearance must be equal to or greater than the thickness of ordinary writing paper.

f. Torque all holding studs to 110 inch-pounds; do not go above this value. Start with the center studs and work outward.

g. Bolt vane in tester and gently lower the weight so that pressure is on the vane. Leave weight on for one minute, then raise weight, turn vane over, and apply pressure on the other side for one minute.

h. Remove vane from tester and again torque all holding studs to the 110 inch-pounds, starting with center studs and working outward; do not torque vane studs above 110 inch-pounds.

i. Complete and sign two vane test sheets; one for filing and the other to be placed with vanes.

j. Install holding ears, nuts and locking strips on vanes.

k. Seal vane box to discourage tampering.

A.3.2 Burners

a. Visual Examination

1. Use only burners that have been static fired.

2. The burner must have three expansion folds (in some units the middle fold is missing).

3. The cooling lines must have an expansion loop.

4. The burner must have a thrust-frame connection.

5. Inspect the entire body of the burner for cracks in the welding. Burners should be rejected if cracks are found at places difficult to work on, such as a burner head inside or outside, combustion chamber and nozzle inside.

b. Cleaning Process

1. If there is much dirt on the outside or in the combustion chamber, remove it with a wire brush and water, or by any similar method.

2. Cleaning with compressed air

To remove all large particles of dirt (dust, earth, metal shavings) blow compressed air in the opposite direction of normal operation into the cooling-jacket, cooling lines and nozzles. To obtain thorough cleaning:

(a) Close the oxygen intakes with blind flanges.

(b) Close the opening for the alcohol valve with a blind flange.

(c) Remove all pressure reducing throttles from the cooling lines.

(d) Remove screw plug at the alcohol intake fold.

(e) Connect burner pressure gage to the blind flange of the alcohol valve opening.

(f) Place burner on top of the test plate and fasten it with turn-buckles. Compressed air is fed through the test plate. Pressure of compressed air in burner is not to exceed 14 psi. Before and during the cleaning, hammer the cooling jacket and the cooling lines with a wooden or plastic hammer to remove loose particles of dirt. Repeat procedure three to four times (four to five seconds of blowing each time) until the escaping air appears clean.

3. Flushing with water

Water should dissolve and flush dirt which is firmly encrusted in the cooling-jacket. To flush:

(a). Attach the flushing device to the opening of the valve seat.

(b) Open the six alcohol intakes.

(c) Open the flushing-screws at every expansion fold. Flush the water through at a pressure of about 150 psi for one or two minutes (two to three times).

c. Pressure Test

1. Subject cooling jacket and lines to 265 psi water pressure

For reasons of safety, make these tests with a water pressure pump. Cooling jacket and cooling lines should be tested separately.

(a) Cooling jacket

(1) Place the testing device in the opening for the alcohol valve.

(2) Close the six alcohol intakes with blind flanges.

(3) Fasten the pressure line to the gage-fitting on the alcohol intake fold.

(4) Exchange ZK nozzles for blind screws.

(5) Fasten manual drain valve at alcohol intake fold.

(6) Pressurize to 265 psi.

(7) When pressure is removed, check burner for evidence of leakage.

(b) Cooling lines

(1) Exchange the hollow screws for blind screws.

(2) Exchange throttles for blanking screws in the orifice rings.

(3) Fasten the pressure supply ring and the pressure line at the orifice nipples on the top ring.

(4) Pressurize to 265 psi.

2. Repeat the same test with 225 psi air pressure. After emptying the burner of all water, subject the cooling-jacket and cooling lines to 225 psi air pressure to detect any small points of leakage. Test all critical points, such as welding seams and connections, with soap solution. Testing procedure is the same as 1. except that air is used instead of water.

3. Burners should be dried. After finishing the above tests, drain the water thoroughly. To remove the water from the expansion loops of the cooling lines, lead compressed air through the cooling line intakes. Remove moisture by blowing hot air into the venturi. Thorough drying takes from 6 to 8 hours. The following are the necessary preparations:

(a) Replace the blind flange (in the opening for the alcohol valve) with the testing device.

(b) Exchange the blind screws for hollow screws in the intakes of the cooling lines.

(c) Install the original throttle orifices in the rings (5 mm orifices in the two bottom rings, and 4.5 mm orifices in the two top rings). Install all orifice cover plugs except the units in the top ring.

(d) Remove the drain plugs at the expansion joints.

4. Pressure-test the venturi-protector with 14-psi compressed air. Check all welding seams with soap and water. If a leak is not indicated, close the pressurizing valve. If the pressure as measured at the testing gage decreases, a leak does exist and is between the venturi-protector and the lower cooling chamber.

5. Pressure-test the entire burner with 14-psi compressed air.

(a) Close orifice cover plugs of top ring with good gaskets.

(b) Put a drain valve or a blind plug on the drain opening at the alcohol intake fold.

(c) Place burner on test plate and connect it to the compressed air supply. Check the safety valve of the system and make sure that it opens and releases pressure at 17 psi.

(d) Maintain test pressure of 14 psi accurately. Specifically, check burner with soap and water for the following:

(1) Leaks at welding seams at the outer head of the burner

(2) Leaks at welding seams of the injection cooling chambers

(3) Leaks at plugs which were open during the drying process

(4) Rising pressure at the outlet opening of the venturi protector. This is a check of the welding seam between the space of the venturi protector and the bottom cooling chamber. After leaks are repaired, perform a test for constancy of pressure. A pressure of 14 psi must remain constant for 15 minutes with the pressurizing valve closed. With the pressurizing valve closed, the pressure (14 psi) should remain constant for 15 minutes.

d. Final Work

After the testing and cleaning is finished, close all openings carefully with blind flanges or plugs and good gaskets, if they were not already closed perfectly during the test. After, protect the burner from all dirt, especially that which might get in through the venturi. The blind flanges at the oxygen inlets stay in.

A.3.3 Air Bottles

a. Pressurize manifold hydrostatically to 4500 psi. Release pressure and dry.

b. Pressurize bottles (with adapters installed) to 4500 psi hydrostatic. Keep pressure on for one minute, release, drain and dry.

c. Assemble bottles to manifold and rack, connect pressure hose and immerse assembly in water tank in steam-plant test room. Pressurize with air to 3000 psi. Observe for leaks through test room window. DO NOT ENTER TEST ROOM WHILE BOTTLES ARE AT THIS PRESSURE. If it is necessary to enter the room to determine location of leak, bleed pressure to 1500 psi. If manifold requires welding to repair leakage, another 4500-psi hydrostatic test will be required as well as another 3000-psi assembly air test.

d. Cap off manifold inlet for storage.

A.3.4 Heat Exchanger

a. Visual Examination

Examine unit and clean if necessary. Watch especially for the following:

1. Heat exchanger must show no traces of grease or oil. If such substances are detected, the unit must be thoroughly cleaned with a grease-dissolving liquid to avoid danger of explosions.

2. The pipe coils and especially the nozzles must not be clogged.

b. Pressure Test

1. Subject casing to 28-psi water pressure

2. Subject pipe coils to 71-psi air pressure. For this test it is advisable to submerge the unit under water to detect small leaks better.

3. After testing, dry the heat exchanger carefully with warm air to prevent oxidation.

c. Performance Test

Test arrangement is shown in Fig. 36. Carefully open valve until the precision pressure gage shows 7.1 psi. Differential pressure at the U-tube (filled with water) must remain constant at 260 $\pm$ 25 mm.

d. Final Operations

Close all intakes and outlets to prevent entrance of dust. A test reports sheet for the heat exchanger is shown in Fig. 37.

A.3.5 Important Pipes and Fittings

a. Test procedure for alcohol two-fold fittings, alcohol three-fold fittings, alcohol lines from two-fold to three-fold fittings, alcohol feed lines, alcohol return lines (both parts), oxygen lines and oxygen three-fold fittings is noted below.

1. Pressurize hydrostatically to 500 psi.

2. Drain and remove cover plates and let dry at least 12 hours.

3. Pressurize with air to 100 psi; check for leakage both by immersing in water and with soap solution.

4. Any leakage necessitates rewelding and complete retest.

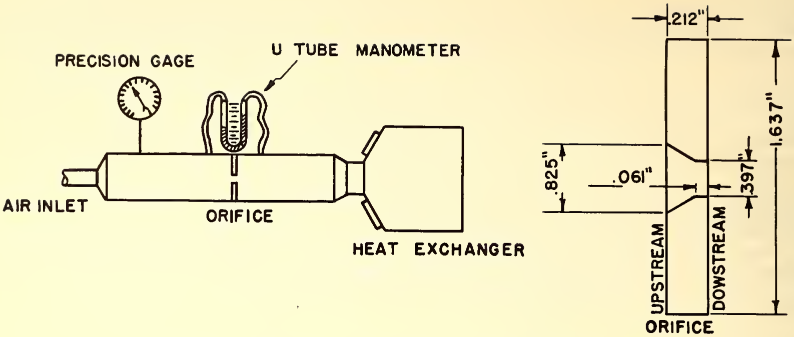


Fig. 36 Apparatus Arrangement for Heat Exchanger Test

TEST REPORT

HEAT EXCHANGER

No. of Heat Exchanger:

Used in Rocket No.

1) Visual Examination
   - a) General Condition
   - b) What repairs were effected?
   - c) Was the heat exchanger cle. ned?

2) Pressure Test
   - a) Casing:
     - Pressure (2 atm. water pressure)
     - Leakage
   - b) Pipe Coils:
     - Pressure (5 atm. air pressure)
     - Leakage
   - c) Drying

3) Performance Test
   - a) Pressure in front of nozzle (0.5 atm.)
   - b) Differential Pressure

4) Final Operations
   - All lines and fittings closed dust-tight

Tested by: Date:

Fig. 37 Heat Exchanger Test Report Sheet

b. Test procedure for steam line:

1. Pressurize hydrostatically to 600 psi, watch for leaks.

2. Any leakage necessitates rewelding and complete retest.

c. Test procedure for alcohol intake pipe with expansion joint:

1. Blank off assembly and put holding clamp on expansion joint.

2. Pressurize with gas to 29 psi and check for leakage with soap solution.

d. Test procedure for expansion joints:

1. 'Blank off expansion joint and affix tie rods.

2. Pressurize with gas to 29 psi; check for leakage by immersing in water on side and rotating so that all soldered joints can be scrutinized. No leakage is allowed.

A.3.6 Alcohol Main Valve

a. Plug openings on side of auxiliary case and on by-pass line. Apply 170 psi to the bottom of the auxiliary case. The main stage must have a stroke of from 28 to 30 mm. Repeat this test five times.

b. Apply 170 psi to the bottom of the auxiliary case. Check the by-pass line for leakage. No more than three bubbles per second are allowed. Check the control pressure connection pipe for leakage. No more than three bubbles per second are allowed.

c. Apply 570-psi control pressure. The prestage must move immediately and the minimum stroke must be 5.5 mm. Repeat this test five times.

Apply 570-psi control pressure. Apply soap solution around case threads and both plugs. Leakage is not allowed.

d. Apply 570-psi control pressure. Plug off air-inlet at bottom of auxiliary case. Check the by-pass line for leakage. No more than two bubbles per second are allowed.

e. Apply 570-psi control pressure. Check the auxiliary case for leakage at the side. No more than two bubbles per second are allowed.

Apply 570-psi control pressure and apply 21 psi at bottom of auxiliary case. Check for leakage at side of auxiliary case. No leakage in addition to the leakage in e. above is allowed.

A.3.7 Alcohol Preliminary Valve

When operating this valve, use test stand. Never place hands between the valve body and the cone when applying control air. Keep hands clear and exercise extreme caution. Improper use can result in serious injury.

a. Remove switch, rewire with stranded wire, and replace, using good grommet. Do not overtighten.

b. Exchange ''U'' cups for units that have not been used.

c. Apply 570-psi control air. Apply 15-psi pressure at the vent line. Check for leakage with soap solution at vent fitting and at all fittings on top of valve. Remove the 15-psi pressure before the 570-psi control air is removed or the center ''U'' cup will be damaged.

d. Apply 70-psi control air. The valve cone must open smoothly. In the open position, the switch must make contact. Bleed the control air. The valve cone must close smoothly. Repeat test five times.

e. Apply 570-psi control air. Check the leakage at the breather pipe connection. No leakage is allowed. Check for leakage at the push rod connection. Leakage is not allowed. Repeat test five times.

A test report sheet for this valve is shown in Fig. 38.

PRELIMINARY ALCOHOL VALVE BP L50			
By Date	Test 1	Test 2	Test 3
1. SMOOTHNESS OF STRIKE, OPENING			
2. SIGNAL LAMP			
3. SMOOTHNESS OF STROKE, CLOSING			
4. LEAKAGE AT BREATHER PIPE			
5. LEAKAGE AT PUSH ROD			
a. Packing gland (inner seal)			
b. Gasket (outer seal)			
REMARKS:			

Fig. 38a Alcohol Preliminary Valve Test Report Sheet

Fig. 38b Alcohol Preliminary Valve

A.3.8 Oxygen-filling Valve

a. Apply 42 psi to the tank side of the valve. Leakage greater than four bubbles per second at the inlet side is not allowed. Soap the valve case. No leakage is allowed through pores in the case.

b. It must be possible to open the valve piston 20 mm without feeling any friction.

c. Check for cracks between the bolt bosses and the case. Cracks are not allowed.

A.3.9 Switch Battery

a. Install switch battery on test fixture. Tighten the two electrical connections, the control pressure connection, the two pressure outlet connections and the four screw connections on bottom of switch battery.

b. Apply 570-psi control pressure. With soap solutions, test all screw connections including: (1) outer rim of four screw connections at bottom of switch battery, (2) electrical connections, (3) screw connections on pressure outlets, (4) screw connections on control pressure inlet, (5) screw connection on plug opposite control pressure inlet and (6) area connecting the two halves of switch battery. No leakage is allowed at any of these locations.

c. Apply 570-psi control pressure. Turn electric switch "ON." Maximum voltage is 18 volts. The switch battery must operate within 0.5 second (with automatic timer used, light will go on if time is too great). Repeat this test five times. Do not leave switch on more than one minute and do not use more than 18 volts.

d. Apply 570-psi control pressure. Throw switch "ON." Check for leakage at the main bleed hole and at the servo bleed hole. No more than two bubbles per second at either hole is allowed.

e. Apply 570-psi control pressure. Throw switch "OFF." Check for leakage at the servo bleed hole. No more than four bubbles per second are allowed. Check for leakage at the main bleed hole. Only two bubbles per second are allowed.

f. Disconnect electrical plugs. Apply 40 atmospheres control pressure. Test the electrical connection for leakage. No more than two bubbles per second are allowed.

g. The resistance of insulation may not be less than five megohms.

A.3.10 Alcohol Drain Valve

a. Apply 355 psi to the inlet side. No more than one bubble per second is allowed at the discharge side.

b. Apply 28 psi to the inlet side. Block the discharge side and open the valve. No leakage is allowed at the pin.

c. Open the valve all the way and then close it. The valve must seat if more than five revolutions are made.

d. The minimum distance between the case and the handwheel must be 1 mm in the closed position.

A.3.11 Ram Charger Valve

a. Apply 570-psi control pressure. The piston must seat quickly and smoothly. The minimum stroke must be 14 mm. Repeat this test five times.

b. Maintain 570 psi and check the valve for leakage. No more than two bubbles per second measured at the intake side are allowed.

c. Maintain 570-psi control pressure. Apply 20 psi above the piston. Check the leakage at the intake side. No more than two bubbles per second in addition to the bubbles found in b. above are allowed.

A.3.12 Alcohol Drain Valve (Tank)

a. Apply 28 psi to the auxiliary case. No leakage is allowed anywhere on the drain side.

b. Smooth movement of the valve should be checked by hand. The minimum stroke must be 4.5 mm.

A.3.13 A-3 Check Valve

a. The valve piston must have a minimum stroke of 4 mm.

b. Apply 35 psi at the discharge side. No more than 0.05 cfm leakage at the inlet side is allowed.

c. Block the discharge side and apply 20 atmospheres pressure at the inlet side. The threads of the case must be tight.

A.3.14 Oxygen Vent Valve

a. Apply 100 psi through the control pressure connection. The valve must open quickly and smoothly. Repeat five times.

b. Insert a metric scale from the outlet side of the valve so that the scale rests on the center stud inside the valve. The scale will then be inside the valve spring. Using a straightedge for ease in reading, take the initial reading. Apply 100 psi at the control pressure connection. Take a second reading. The difference in the initial and second readings (valve travel) must be at least 10 mm. Repeat five times.

c. Place the test flange with a rubber gasket on the inlet side. Apply 355 psi through the 0.8 mm orifice on the inlet side. The pressure in the chamber must remain constant between 28.4 and 31.2 psi measured with a precision pressure gage.

d. Leaving the test flange on the inlet side, install an additional test flange on the outlet side. Use a rubber gasket. Apply 575 psi through the control pressure connection. Install the bubble indicator. No more than four bubbles per second are allowed. Make sure the openings on the test flange at the inlet side are plugged.

e. Remove bubble indicator and install flowmeter. Apply 15 psi at the inlet side. Increase the pressure until the chamber pressure is 17 psi (actual inlet pressure may have to be increased to as much as 100 psi to get 17 psi in the chamber). Read the flowmeter. Maximum allowable flow leakage past seat is 2.54 cfm.

A.3.15 Oxygen Main Valve

a. Hot Tests

1. Replace the double lip seal with an American-made seal, lubricate seal and cylinder with Aquadag and reassemble.

(a) Apply 570-psi control pressure. Check the leakage at the fitting mounted on one of the six flanges. No more than four bubbles per second are allowed.

2. Apply 570 psi at control pressure line and check electrical plug for leakage. In most cases this plug will have to be tightened or the gasket replaced. Be careful not to strip the aluminium threads.

3. (a) Bleed the control pressure line. Blank off the side fitting on the flange which was open in 1. and apply 170-psi pressure through the main flange (top). The minimum stroke of the main stage must be 31 mm. No binding is allowed. Valve should open quite smoothly, repeat test five times.

(b) Maintain 170 psi and check the control pressure connection-pipe for leakage. No more than four bubbles per second are allowed.

(c) Check case and bottom gasket(between housing and center sections of valve) for leakage. No leakage is allowed.

4. (a) Bleed the 170-psi pressure and apply 570 psi at the control pressure line. Apply 21 psi through the main flange. Check the leakage at the side fitting. Maximum leakage allowed is seven bubbles per second in addition to the leakage obtained in 1. above.

b. Liquid Oxygen Test

1. Place special potentiometer on bottom of valve to measure the operation of the main stage stroke. Fasten valve to the lox container. Supply air to the control pressure line by means of a set of three air bottles (21 litres). This set of bottles is pressurized with dry air to about 2000 psi. A regulator and switch battery is mounted on the bottles. A recorder is connected to the potentiometer. Dry air is supplied through a regulator and solenoid valve to pressurize the tank. A solenoid-operated bleed valve is mounted at the heat-exchanger connection (on the top of the tank). All these valves are operated electrically.

2. Procedure

(a) Open hand valve on set of three bottles and supply 570-psi control pressure to main oxygen valve.

(b) Operated solenoid valve to close off connection on heat exchanger.

(c) Start recorder and operate switch battery, which will open preliminary part of the valve. Operate solenoid valve to close top vent and start pressurization. Main stage valve should open at 100 psi maximum. Recorder will show the smoothness of opening. No sudden jerks should be present at normal temperatures. Also, while valve is open, check the presence of severe leaks. After valve is pressurized to 100 psi, stop pressurizing and stop recorder. Bleed air from tank by operating bleed valves and de-energize switch battery.

(d) Connect flowmeter to heat exchanger after removing bleed valve. Record the pressure in the three air bottles. Put in lox at top of tank and fill completely. Take readings for one hour, recording flowmeter and pressure drop in air bottles every three minutes.

(e) Flowmeter reading should not exceed 2.0 cfm. Next, remove flowmeter and connect bleed valve again. Pressurize tank also. This time the valve must start opening at 100 psi and be completely open at 150 psi. The stroke on the recorder will be quite rough. Check for any long period of stickiness.

(f) Remove valve and dry thoroughly. Install electrical contact and set preliminary stroke to operate between 2.5 and 3.5 mm. Make hot tests again. Install calrod unit. Megger electrical connection and calrod unit. Assemble adapter and 25-ton valve on bottom of lox valve. With 570 psi control air, check gaskets and adapter on valve.

A test reports sheet for this valve is shown in Fig. 39.

A.3.16 Steam Plant

A.3.16.1 Preparation

a. Inspect interior of peroxide tank for dirt, rust and corrosion. Tank must be clean and must have black coating.

b. Clean exterior of steam plant with a wet cloth.

c. Check all electrical connections and insulate leads to the solenoid valves and regulator heater.

d. Replace the PE-10, Z contact and eight-ton valve with parts tested previously.

e. Replace the glass on both the 250 and 60 atmosphere gages with plexiglass and drill a small hole for venting in case the bourdon tube should break.

f. Make sure all fittings are reasonably tight.

g. Install a special cross in the control line that runs from the regulator-gage line to the PE-4 lines. Plug off that side of the cross in which the 0.017-inch diamter hole is located and one other side.

h. Calibrate the recording gages.

i. Connect gages to steam plant. Connect high-pressure line to intake of steam plant. Plug off steam generator with special orifice. Connect valve to allow air to escape through this orifice when testing steam plant.

j. Make sure a clean filter is in the air supply line.

k. Remove safety valve NO-10, test according to instructions, and reinstall before making any steam plant tests.

l. Megger and check resistance of each valve.

OXYGEN MAIN VALVE 4413C

TEST SHEET

VALVE NUMBER ______

1. A. Stroke of Pre-Stage

   B. Signal Lamp

   C. Leakage of Control Pressure

2. Leakage Past Seat

   a. Leakage Past Inner Seat

3. A. Length of Stroke

   Smoothness of Stroke

   B. Leakage Into Control Pressure Chamber

4. Insulation Resistance

5. Leakage Past Electrical Connection

6. Leakage at Case Threads

7. Leakage Between Valve & Case

8. Case Leakage

REMARKS:

DATE: ____________ TESTED BY: ____________

Fig. 39 Test Report Sheet for Liquid Oxygen Valve

A.3.16.2 Leak Tests

a. Fill both air batteries to approximately 1500 psi. Close high-pressure hand valve on steam plant.

b. Close switch 2 on test box. This action supplies air from one set of air bottles.

c. Open high-pressure hand valve.

d. Set pressure regulator to 550 psi.

e. Close steam plant bleeders, D1h.[12]

f. Close bottom of steam generator.

g. Open main stage valve Dh. Steam plant will start to pressurize.

h. When pressure levels off, shut off Dh valve and open up eight- and 25-ton valves. Check recording gages for any pressure drop which would indicate leakage of air. CAUTION: Never enter the steam plant room when a pressure of this magnitude exists in the tanks.

i. Bleed all air in the tanks (through the steam plant bleeders) by opening D1h.

j. Reset regulator to 485 psi.

k. Pressurize tanks again to 300 psi.

l. With soap and water, check all fittings, valves, lines, bleedholes and welds for leakage. Make sure eight- and 25-ton valves are open. CAUTION: Always keep away from steam plant bleeders; loss of power or severe leakage of air will cause bleeders to open.

m. Bleed air from steam plant and repair leaks.

n. Repeat steps l. through m. until all leaks have been eliminated.

A.3.16.3 Valve Checks

a. Close high-pressure hand valve, bleed air through the small hand valve on the regulators. Determine if the pressure on low-pressure gage drops to zero and bleeding stops. This is a test for leakage past the high-pressure hand valve.

b. Open high-pressure hand valve again and pressurize steam plant to 300 psi. With 18 volts, check for quick and smooth operation of solenoid valves.

c. De-energize Dh. Break the connection between Dh and the Z and T check valves. If there is any leakage at this break, either the PE-10 or the two check valves are faulty.

d. Leakage from the 25-ton valve past the discharge side can be checked by closing the 8-ton valve and capping off the line on top of the permanganate tank. Check for leakage after removing cap on line just below the 25-ton valve. No more than two bubbles per second are allowed.

e. Replace and tighten all fittings. Check for leaks with soap and water. Close high-pressure hand valves.

A.3.16.4 Operational Tests

a. Start heater on reducer, and operate at 28 volts for five minutes.

b. Fill air bottles between 2850 and 3125 psi.

c. Close off compressor supply and open valve 2.

d. Open high-pressure hand valve.

e. Set regulator to 469 psi on recorder (with small needle valve open). With needle valve closed, pressure should not exceed 490 psi.

f. Ink recorders.

g. Close bleeders on steam plant.

h. Close bottom of steam generator.

i. Open Dh valve (pressurization has started).

j. Open eight- and 25-ton valves

k. Throw switch to air bottles 1 and cut off 2.

l. Throw switch for 110 volts to recorder.

m. Open bottom of steam generator; start recorder.

n. Allow air bottles to drop to 700 psi.

o. Close 25-ton valve. Steam pressure should not drop below 285 psi. Close eight-ton valve. Steam pressure should not drop below 125 psi.

p. Close Dh valve.

q. Stop recorders.

r. Open steam plant bleeders (test has ended).

s. Remove ink from recorders.

t. Take pressure off regulator.

u. Megger all valves.

v. Remove test lines.

w. Put protective fittings on all open ports and safety-wire all fittings.

A test report sheet for the steam plant is shown in Fig. 40.

A.3.17 Reducer Safety Valve

a. Apply 490-psi pressure. The seat must be absolutely tight.

b. Increase the pressure slowly. Between 500 and 555 psi a blowing must be heard. As the pressure is increased the blowing must also increase.

c. Reduce the pressure to 285 psi. Between 555 and 285 psi the valve must close and be absolutely tight.

A.3.18 Hand-operated Valve on Reducer Assembly

a. Block the discharge side and apply 570 psi to the inlet side. Open and shut the valve three times.

These operations must be done easily by hand. One revolution of the handwheel is a minimum necessary to open or to shut the valve.

b. Open the valve; no leakage at the packing gland is allowed.

c. Close the valve; leakage may not exceed one bubble per second at the discharge side.

A.3.19 High-pressure Hand Valve

a. The minimum measured stroke of the fill piston must be two mm.

b. Block the discharge side and apply 2850 psi to the inlet side. Close and open the valve several times by turning the handwheel. The wheel must move easily and smoothly a minimum of three revolutions.

c. Maintain 2850 psi and check for leakage at the case threads and at the packing. No leakage is allowed.

d. Close the valve, open the discharge side and apply 2850 psi to the inlet side. Check the discharge side and the fill connection for leakage. No more than one bubble per second at either place is allowed.

A.3.20 <u>Peroxide and Permanganate Bleed Valves</u>

a. Apply 570 psi to the control pressure side. The piston must move quickly and smoothly. Minimum stroke of the piston is 6mm. Bleed the control pressure side. The piston must return quickly and smoothly. Repeat this test five times.

b. Apply 570 psi to the control pressure side. Check for leakage at the discharge side. No more than two bubbles per second are allowed.

c. Maintain 570 psi at the control pressure and inlet sides. Test the leakage at the discharge side. No more than two bubbles per second are allowed in addition to the leakage in b. above.

A.3.21 <u>Peroxide and Permanganate Drain Valves</u>

a. Apply 57 psi to the working-pressure side. No more than one bubble per second is allowed at the valve seat. No leakage is allowed at the case threads.

A.3.22 <u>Peroxide and Permanganate Check Valves</u>

a. The check valve must have a minimum stroke of 2mm. The force necessary to open it must not be more than 1200 grams.

b. Apply 570 psi at the discharge side. Test the leakage at the inlet side. No more than two bubbles per second are allowed. No leakage is allowed at the case threads.

TEST REPORT

STEAM PLANT

No. of Steam Plant:

Built into Rocket No.:

1) Visual Examination
   a) Result of interior inspection of tank
   b) What parts were missing?
   c) What parts were replaced?
   d) General condition of the plant

2) Test for Leakage
   a) Test Pressure (b) Pressure leak atm. in minutes
   c) Necessary repairs

3) Performance & Operation Test
   a) Setting of pressure reduction valve
      1) Pressure with ventilation screw closed (static)
      2) Fluctuation of pre-set pressure
   b) High pressure:
      1) Start of test (2) End of test
   c) Low pressure (1) (2) (3)
   d) Peroxide tank pressure (1) (2) (3)
   e) Steam pressure (1) (2) (3)
   f) Steam pressure of the 8-ton stage

4) Final Operation
   a) Pressure reduction valve released
   b) All gauge fittings closed
   c) All other fittings protected

Tested by: Date:

Fig. 40 Test Report Sheet, V-2 Steam Plant

A.3.23 25-ton Valve

a. Apply 70-psi control pressure, bleed and repressurize 10 times quickly. Listen for rattle-free moving of the piston. Minimum stroke is 5.5 mm.

b. Apply 570-psi control pressure. Check for leakage at the bleedhole (two mm diameter). No more than three bubbles per second are allowed.

c. Block the discharge side and the pipe-connection side of the valve. Apply 570 psi to the inlet and control pressure sides. No more than one bubble per second at the two mm bleedhole is allowed.

d. Bleed the control pressure. Apply 570-psi at the inlet side. Check for leakage at the discharge side. No more than one bubble per second is allowed.

A.3.24 PE-4 Control Valve

a. Apply 570-psi to the inlet side. Blank off outlet and soap the bleedholes. No leakage is allowed. Remove blanking plug.

b. Maintain 570-psi control pressure. Connect outlet to 1 litre pressure flask. Throw the electric switch to the "ON" position (maximum voltage, 18 volts). The valve must operate without delay. Throw the switch to the "OFF" position. Now the valve must bleed quickly and smoothly.

c. Apply 570 psi to the inlet. Throw the electric switch to the "ON" position. No leakage at the bleedholes is allowed.

d. The resistance of the insulation must be more than five megohms.

A.3.25 Eight-ton Valve

a. Apply 570 psi at the inlet side. No more than one bubble per second at the discharge side is allowed.

b. Maintain 570-psi pressure. Throw the electric switch to the "ON" position (maximum voltage, 18 volts). The valve must operate without delay.

c. Block the discharge side. Maintain 570-psi pressure. Throw the electric switch to the "ON" position. No leakage is allowed at the case threads. No leakage is allowed between the coil and the case.

d. The resistance of the insulation must be more than five megohms.

A.3.26 High-pressure PE-10 Valve

a. Apply 570 psi to the inlet side. No leakage is allowed at the valve seat or at the bleedholes.

b. Maintain 570 psi at the inlet side. Throw the electric switch to the "ON" position (maximum voltage is 18 volts). The valve must operate immediately. A delay of more than two seconds is not allowed (check this by the sound). Throw the switch to the "OFF" position. The valve must shut immediately. Repeat this test five times.

c. Block outlet side. Apply 570 psi to the inlet side. Throw the electric switch to the "ON" position. No leakage at the bleedholes is allowed.

d. The resistance of the insulation must be more than five megohms.

A.3.27 "Z" Contact

a. Apply 570 psi to the inlet side. No leakage is allowed at the case threads.

b. Connect a signal lamp in series with the pressure-switch contacts. Apply pressure to the inlet side and observe the gage. At a pressure of 18.5 to 24 psi the lamp must light. Repeat this test three times.

A.3.28 Throttle in Line to Preliminary Alcohol Valve

a. Connect: (1) a measured volume of 0.9 to 1.1 litres and (2) a gage to the discharge side of the throttle. Apply 570 psi to the inlet side rapidly. The gage must show 570 psi within two seconds. Bleed quickly; the measured volume must be empty in 10 to 15 seconds. Repeat this test five times.

b. Close the discharge side of the throttle. Apply 570 psi to the inlet side. No leakage is allowed at the case threads.

A.3.29 Check Valve on Cross Piece

a. Connect: (1) a measured volume of 0.9 to 1.1 litres and (2) a gage to the discharge side of the check valve. Apply 570 psi to the inlet side rapidly. After two seconds, the pressure in the measured volume must be 525 psi. Repeat this test three times.

b. Apply 570-psi pressure to the discharge side. No more than two bubbles per second is allowed at the inlet side; no leakage is allowed at the case threads.

A.3.30 Alcohol Tank

a. Test sequence (test report sheet for this tank is shown in Fig. 41).

1. Visual examination.
2. If tank is in good condition, rivet according to Drawing No. P-SK-336.
3. Air-test at 1.5 psi and repair leaks.
4. Hydrostatic-test at 21 psi and hold for 15 minutes.
5. Air-test at 12.8 psi and hold for 15 minutes. Check for leaks with soap solution.
6. Repair leaks and repeat d. and e. until leaks do not occur.

TEST REPORT

ALCOHOL TANK

No. of Alcohol Tank:

Used in Rocket No.:

1) What repairs were effected?

2) Inside of tank was cleaned thoroughly

Was found to be in perfect shape

3) Preliminary Valve Test:

Valve worked perfectly

Inside control and vent lines in tank were checked

4) Tested Fuel Level Guage was built in

5) Last Pressure Test:

Test Pressure

Leakage

6) After final test all openings (especially measuring fitting, fueling fitting and outlet fitting wers closed

Tested by: Date:

Fig. 41 Alcohol Tank Test Report Form

A.3.31 Oxygen Tank

The vent valve must be in place whenever air pressure is being applied to the oxygen tank. It shall be the sole duty of one man to stay within reach of the air-supply hand valve and to watch the pressure gage. This safety precaution will be observed from the moment the air hose is connected to the tank until the air is completely bled from the tank.

Flexible hose will be used in all pressurization.

Two gages (each on separate pressure tops) will be connected to the tank when air is being applied. These gages will be tested by V-2 personnel immediately prior to pressurization.

Barricades will be used when the fluctuating-air test is being made at the calibration stand and when the tank pressure is being brought up to 21 psi in the hangar.

The area will be cleared and roped-off and adjacent offices will be vacated, when 21 psi tank pressure is used during test in the hangar.

When the air test is being made at the calibration stand, the area will be cleared and roped-off.

a. Test Sequence

1. Visual examination.
2. If in good condition, rivet according to Drawing No. P-SK-335.
3. Air-test at 1.5 psi and repair leaks.

Do not start the hydraulic test (step 4. below) until it has been determined that the midsection will be ready when the tests (through step 7. below) are finished.

4. Hydraulic-test at 32.7 psi and hold pressure for 20 minutes.
5. Apply pressure for one minute over range of 4 to 21 psi. Repeat five times.
6. Repeat hydraulic test at 32.7 psi. Hold for 20 minutes.
7. Bring tank into hangar and air test at 21 psi, and hold for 20 minutes. Check for leaks with soap solution. If any leaks develop, repair and start test again at step 4.
8. Put tank in midsection.

A test report sheet for the lox tank is shown in Fig. 42.

TEST REPORT

OXYGEN TANK

No. of Oxygen Tank

Used in Rocket No. :

1) What repairs had to be done?

2) Inside of tank was thoroughly cleaned?

was in good shape?

3) Last Pressure Test. Test Pressure

Leakage

4) After final test, all openings (especially the intake fitting) were closed

Tested by: Date:

Fig. 42 Oxygen Tank Test Report Form

APPENDIX B
PROPULSION UNIT CALIBRATION

B.1 GENERAL

To obtain optimum missile performance, it was necessary to insure that the propellants were supplied to the combustion chamber in the proper quantities and proportions. Variations in pump characteristics and in pressure drop through the motor jacket were large enough to make individual calibrations of each propulsion unit necessary.

In the German procedure, each major component (the turbine-pump assembly, the motor and the steam plant) of the propulsion unit was tested separately. From the data thus obtained, calculations determined the correct size of flow-regulating orifices to be used in the main propellant lines. These orifices regulated the relative flow in the two propellant lines and thereby determined the mixing ratio. The total-flow rate was adjusted by varying the pressure of the gas supplied to the steam plant. From the steam-plant test data and the size of the orifices selected, a calculation determined the gas pressure required to produce the desired flow and thrust.

At the start of the V-2 program at WSPG, test papers were available on enough turbo-pumps and motors to complete thirty missiles. From these data, calculations were made and orifices were selected for the first 30 missiles. Results by this method of selection were not consistent. It seems probable that the inconsistency was due primarily to changes in the pressure drop in the alcohol jacket of the motor. Many months had elapsed since the German tests and some change in the surfaces of the inner walls might be expected.

Complete test data were not available for the steam plants. Therefore, an air test was necessary to determine the characteristics of the steam plants. From these data, the setting of the gas-pressure regulator was determined.

To arrive at a mixing ratio of acceptable accuracy (for those missiles beyond the thirtieth) it was necessary to establish calibration facilities and procedures at WSPG.

B.2 METHODS OF CALIBRATION

Among the various methods of calibration, the following were considered for use at WSPG.

B.2.1 Hydraulic Testing of Component Parts

In this method, each of the major components was water-flow tested under specified conditions. The test results would then be used, as in the German procedure, to calculate orifice sizes. This method offers certain advantages when mass production is involved, but these advantages could not be fully realized on a relatively small number of missiles at WSPG.

B.2.2 Water-flow Test of Complete Propulsion Unit

The results obtained by this method are more accurate than those obtained by section B.2.1 above, due to the fact that the sum of the measuring errors for individual components is reduced substantially. This method also requires less special test equipment.

B.2.3 Cold Propellant Test of Complete Propulsion Unit

This method is the same as B.2.2 above except that actual propellants would be used in the place of water. A slight increase in accuracy should result, since some conversion factors would be eliminated from the calculations. The cost would be considerably greater and a certain amount of fire hazard would be involved.

B.2.4 Static Firing

An actual burning test would undoubtedly produce the most accurate results. All other methods require experimental corrections which must be obtained by static firings. Unfortunately, this method involves the greatest cost, the greatest hazard and the most preparation time.

B.3 CALIBRATION AT WSPG

The calibration procedure selected for use at WSPG was a combination of methods outlined in B.2.2 and B.2.3. The procedure consisted of operating the steam plant with 78 percent hydrogen peroxide and with 32.5 percent sodium permanganate, as in normal flight. Combustion pressure was simulated by means of 18 orifices in the oxygen system and two orifices in the alcohol system. Alcohol (75 percent) was used in the alcohol system but water was substituted for oxygen in the oxygen system. The oxygen nozzles were mounted in special extended housings, to which 1.5-inch fire hose was attached to carry the water to the 18 combustion-simulating orifices. These orifices were located around the periphery of a double funnel which was used to keep the test fluids separate. The combustion-simulating orifices for the alcohol system were located at the flanged connection of the three-way fittings in the alcohol feed lines. The calibration installation is shown in Fig. 43 and in Fig. 4, p. 8.

The first calibration using this method was made on May 23, 1947. This procedure was followed for approximately one year with no basic changes. In general, the results were satisfactory, but it was obvious that improvement was possible in several respects. Preparation time was excessive, primarily due to the necessity of keeping two fluids separate. Accuracy was influenced by the fact that the pressure drop was recorded for only one of the 18 oxygen orifices. The use of alcohol involved expense as well as a fire hazard. It was necessary to disassemble parts of the steam plant to clean it properly after the calibration run.

In July, 1948, a new method of calibration was used for the first time. Water was used as a substitute for both alcohol and oxygen. Combustion pressure was simulated by two orifices; one located in the discharge line of each pump. A separate steam plant was installed as a permanent part of the calibration stand.

Major objections to the original calibration method were eliminated by these changes. The use of a single fluid reduced the setup and preparation time by about 75 percent. Water in the place of alcohol eliminated the expense and fire hazard involved. The use of two orifices in place of 20 increased the accuracy of calibration. A separate steam plant reduced the effort required to condition the steam plant for flight and also allowed a 50 percent saving in the cost of hydrogen peroxide.

When the original procedure was adopted, it was felt that the ideal method required the calibration to be made with all propulsion unit components installed in final flight condition. In theory this was probably correct, but experience proved that it was not feasible. The steam plant had to be cleaned, requiring disassembly. Thus, one of the advantages of the complete-unit test was lost when the piping was disturbed. The advantage of using the flight steam plant for determining total flow rate was of secondary importance since (within limits) flow rate was of much less importance than mixing ratio. Furthermore, a large number of tests had demonstrated that the existing air test on the steam plant gave results well within the required accuracy and well within the consistency limits of the gas-pressure regulators. Therefore, there was no real benefit to be realized through the use of the flight steam plant. On the other hand, there were definite benefits in the use of a separate steam plant. It had been found that a calibration run of 45 seconds allowed ample time to obtain all the desired data, provided a small hydrogen peroxide tank could be used (the regular tank, when only half filled, introduced a starting transient of excessive duration). With a stainless steel tank of 17-gallon capacity (Fig. 44) runs were made with one-half the normal quantity of peroxide. In addition, many man-hours were saved by the reduction in cleaning and retest time.

The new calibration method proved very satisfactory and no basic changes were made during the rest of the program. Details of this final system are described in section B.4.

Fig. 43 Propulsion Unit Calibration Stand

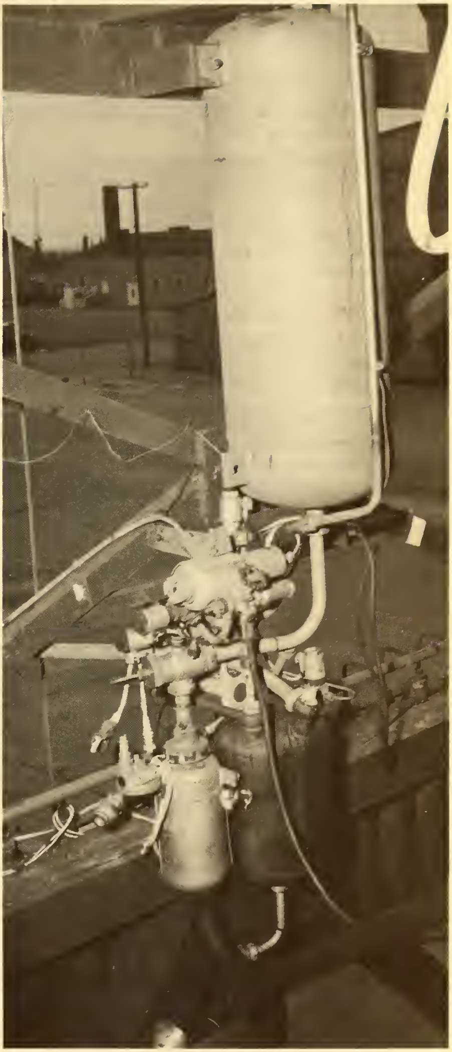


Fig. 44 Stainless Steel H_2O_2 Tank Mounted on Calibration Stand

B.4 DETAILED INFORMATION ON THE FINAL CALIBRATION PROCEDURE

B.4.1 Steam Plant Test

All steam plants used at WSPG had been adjusted previously in Germany. The purpose of the WSPG air test was to see that all valves operated satisfactorily and that pressure drops throughout the system were within specified limits. Steam plants with pressure drops outside these limits were set aside and used as a source of spare parts.

The air test simulated the operation of the steam plant during actual firing except that compressed air was used instead of hydrogen peroxide and sodium permanganate. Steam pressure was simulated by a 4.25 mm orifice mounted in the discharge of the steam generator.

To pressurize the complete steam plant, the downstream side of this orifice could be blocked by a solenoid valve. The pressure regulator was set at 470 psi with the bleed valve open. The difference between this pressure and the pressure with no flow should not exceed 30 psi. With air flowing and with both the 25- and 8-ton valves open, the low air pressure should be between 430 and 465 psi, tank pressure between 410 and 445 psi and steam pressure from 375 to 425 psi.

With the 25-ton valve closed, the steam pressure should drop to between 275 and 325 psi. With both the 8- and 25-ton valves closed, the steam pressure supplied by flow through the permanganate tank should be from 115 to 165 psi.

B.4.2 Combustion Pressure Simulating Orifices

The combustion chamber pressure for a normal V-2 flight or static test is 202 psi. In calibrating a propulsion unit it is advantageous to operate the steam plant and turbo-pump under normal load. Since there is no positive burner pressure, the normal pressure is simulated by means of orifices inserted in the discharge line of the alcohol and oxygen pumps. The calibration test must be made under normal flow conditions since the pressure drop across an orifice varies as the square of the flow, whereas the combustion chamber pressure (for a hot run) varies directly with the flow. In addition, these orifices contain other correction factors for the alcohol and oxygen systems as noted below (all values in psi).

OXYGEN

Combustion pressure		+202
Pressure at oxygen nozzle		+14
*Experimental correction		-7
Tank not pressurized		-20
Eight feet added head at calibration		+4
ΔP with oxygen		193
ΔP with water	193/1.14	169.3

*Injection pressure is 7 psi higher for calibration than for firing.

ALCOHOL

Combustion pressure		+202
**Experimental correction		+7
Eight feet added head at calibration		+3
ΔP with alcohol		212
ΔP with water	212/0.86	246.5

**The cooling jacket pressure drop at burning is higher than at calibration even though the cooling nozzles and ZK nozzles are blocked during calibration.

Alcohol flow through the cooling lines and ZK nozzles comprise about 10 percent of the total alcohol flow. This flow is blocked during calibration because of the difficulties involved in attempting to simulate the pressure drop which occurs across the cooling nozzles during actual combustion. The experimental corrections were obtained from the results of numerous calibrations and static tests at Peenemunde, Germany[13], and have subsequently been confirmed at WSPG.

The orifices used to simulate combustion pressure are calculated by the equation:

$$W = 0.668\ AK\sqrt{\rho \Delta P} \quad \text{as} \quad D = \sqrt{\frac{1.906W}{K\sqrt{\rho\ \Delta P}}} \tag{1}$$

where A = area, inches^2
D = diameter, inches
K = flow coefficient (coefficient of discharge and approach factor)
ρ = density of medium flowing, pounds per cubic foot
ΔP = differential pressure, psi
W = flow rate, pounds per second

Orifice diameter may be calculated on the basis of either water or actual propellant provided the corresponding flow rate, density and ΔP are used:

	OXYGEN FLOWING	OXYGEN WATER FLOWING	UNITS
W	152.5	133.8	pounds per second
ΔP	193	169.3	psi
ρ	71.1	62.4	pounds per cubic foot
Sp. Gr.	1.14	1.0	-

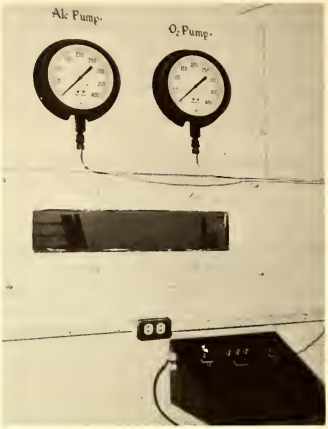
	ALCOHOL FLOWING	ALCOHOL WATER FLOWING	UNITS
W	123.5	143.6	pounds per second
ΔP	212	246.5	psi
ρ	53.7	62.4	pounds per cubic foot
Sp. Gr.	0.86	1.0	-

B.4.3 Instrumentation

Two types of equipment are included under this heading. This section will cover the equipment needed to control the test and the equipment required to record test data.

The control desk (Fig. 45) was located in the control house about 50 feet from the calibration stand (Fig. 11, p.21).

The sequence of operations noted below was controlled from this desk. The turbine overspeed device (TOS in Fig. 46) was equipped with a normally closed contact. With the rotary switch in position P-1 and TOS reset, the start button completed the circuit to energize the "Line Energizer" relay (LE) and supply power for the test. Turning the switch to P-2 operated R-1 to close the bleeders of the steam plant through action of valve D1h. Moving the switch to P-3 operated R-2 to open the alcohol preliminary valve (S1h). The opening of S1h caused its contact, S1r, to complete a circuit to open the oxygen valve O3h to its preliminary stage position. Water then flowed through the system under gravity head. Going to P-4 operated R-3, provided the oxygen valve had opened and thereby closed its contact O3r. In turn, R-3 opened the steam plant pressurizing valve (Dh) which caused the peroxide and permanganate tanks to be pressurized. When pressurization was completed, pressure switch D2r closed its contact and applied power to open the 8- and 25-ton valves, D8h and D25h. The opening of these valves allowed peroxide to enter the steam generator where it was mixed with permanganate to generate steam and start the turbine. The test could be terminated at any time by de-energizing LE through operation of the STOP button or by action of TOS in the event of overspeed. Operation of R-3 also closed contacts to apply 115 volts (ac) to the recorders, thus starting them simultaneously with the start of the turbine.



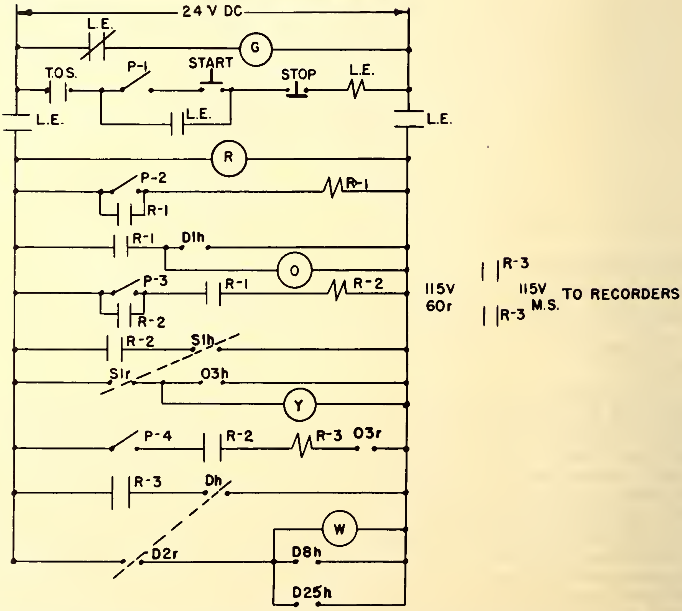


Fig. 45 and 46 (Top to bottom) Propulsion Unit Calibration Control Desk. Schematic Diagram Control -Desk Electrical Systems

One of the most important measurements was the rate of flow from each tank. This was accomplished by means of a float which followed the surface of the liquid: a chart (Fig. 47) on which a mark was made every second was attached to the float. From previous calibrations, the quantity of liquid versus float position was known. The rate of flow could therefore be determined. A secondary flow-measuring system was also employed. Six float switches were placed at known intervals in the tank. Each switch caused a pip to be recorded as the liquid level passed that switch. Since both the amount of water between switches and the recorder chart speed were known, the flow rate could be determined.

Turbine speed was measured by two methods. The most accurate determination was made by means of a contact on a 100:1 gear reduction unit attached to the turbine shaft. This contact caused a pip to be recorded every 100 revolutions. By counting the pips and knowing the recorder-chart speed, an accurate average of turbine speed could be obtained. The second method was the use of a tachometer-generator attached to the turbine shaft. Although less accurate, the second method was valuable in that it gave a continuous record, thus indicating any speed variations.

Steam temperature and steam exhaust temperature were measured by means of sheathed thermocouples inserted in the lines. These values were recorded on a photoelectric recorder.

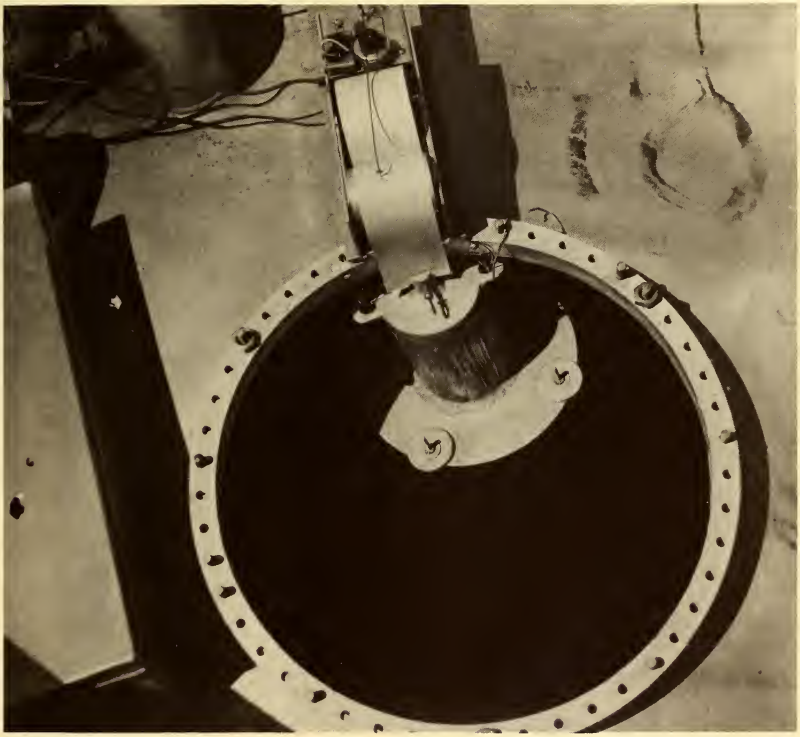


Fig. 47 Float and Recorder Used to Measure Flow from Calibration Stand Tanks

The pressures noted below were measured by means of Brown circular-chart recording pressure gages (Fig. 48), located in a small room on the first level of the calibration stand (Fig. 11, p. 21).

- Oxygen Pump Inlet Pressure
- Alcohol Pump Inlet Pressure
- Oxygen Pump Discharge Pressure
- Alcohol Pump Discharge Pressure
- Oxygen Pressure below Combustion-simulating Orifice
- Alcohol Pressure below Combustion-simulating Orifice
- Oxygen Injection Pressure
- Alcohol Injection Pressure
- Alcohol Cooling Jacket Pressure
- High-pressure Air Supply
- Low-pressure Air Supply (pressure regulator setting)
- Hydrogen Peroxide Tank Pressure
- Steam Pressure
- Steam Exhaust Pressure

Not all of these measurements were required in the calculation of orifice size and pressure regulator setting. However, all were useful in determining that all components of the propulsion system were operating properly. They were also useful in the analysis of troubles discovered during calibration runs. As an example, severe erosion of turbine blades was encountered during early runs. It was found that the blades were rather sensitive to temperature. In those early runs the use of 80.5 percent hydrogen peroxide resulted in an average steam temperature of about 440°C. When the concentration of the hydrogen peroxide was reduced to 78 percent, the temperature of the steam dropped to an average of about 370°C. By holding the temperature below 400°C, blade erosion troubles were eliminated.

The data obtained during calibration runs were also compared with similar data obtained during flight by means of telemetry. This comparison proved useful in accounting for missile performance.

Fig. 48 Interior View of Calibration-stand Instrument House

B.4.4 Preparations for Calibration Test

The procedure outlined below was followed in preparing the propulsion unit for calibration.

The turbopump assembly was dismantled and all bearings and seals were greased to protect them from corrosion during the test (the assembly was completely cleaned and all grease removed after calibration). The propulsion unit was completely assembled (as for flight) with the following exceptions:

a. Special main oxygen and alcohol valves were installed. This was necessary because (during calibration) the simulated combustion-pressure drop occurs ahead of these valves, resulting in insufficient pressure to operate the normal flight valves. The special oxygen valve had a lighter spring and the alcohol valve was bolted open. These modifications did not affect the validity of the test results.

b. A steam plant was not mounted in the unit (a separate plant was used for calibration).

c. The four alcohol cooling lines were blocked off with blank plugs at the head of the motor.

d. One special oxygen feed line, containing the oxygen injection-pressure tap, was installed.

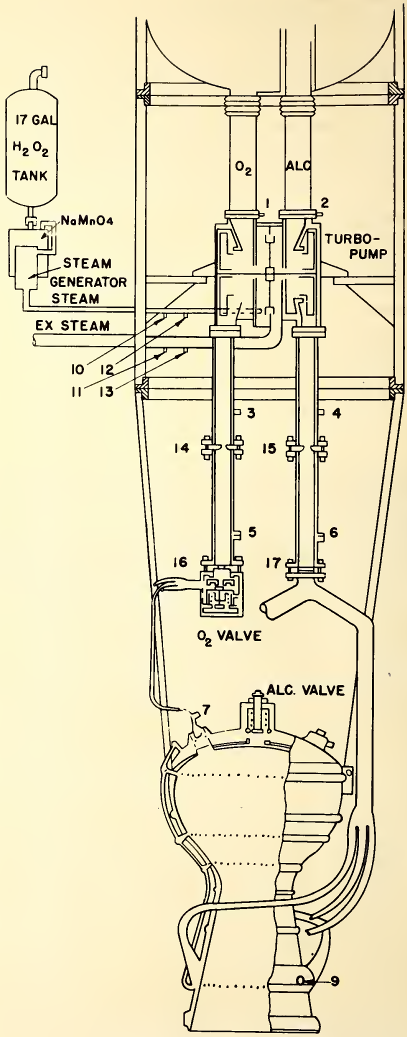
e. Heat exchanger and the exhaust steam lines were omitted.

f. Blank nozzles were substituted for the regular open ''ZK'' nozzles.

The propulsion unit was installed in the calibration stand as shown by Fig. 49 and 50. The turbopump assembly was raised five feet above its normal position and two special lines, containing the combustion-pressure orifices, were installed (Fig. 51 and 52).

A 125-mm (open line) flow-regulating orifice was inserted at the discharge flange of the alcohol pump. A special 78.1 mm, stainless-steel orifice was inserted at the discharge flange of the oxygen pump. From previous tests it had been found that these particular sizes were close to the average of those originally selected and were, therefore, most likely to be near the correct size.

Fig. 49 Propulsion Unit Installed in Calibration Stand



PRESSURE TAPS

1 O_2 PUMP INLET
2 ALC PUMP INLET
3 O_2 PUMP
4 ALC. PUMP
5 O_2 AFTER ORIFICE
6 ALC. AFTER ORIFICE
7 O_2 INJECTION
8 ALC
9 ALC. COOLING JACKET
10 STEAM
11 EXHAUST STEAM

TEMPERATURES

12 STEAM
13 EXHAUST STEAM

ORIFICES

14 O_2 COMBUSTION
15 ALC. COMBUSTION
16 O_2 FLOW REGULATING
17 ALC. FLOW REGULATING

Fig. 50 Schematic Diagram of V-2 Propulsion Unit Calibration Arrangement

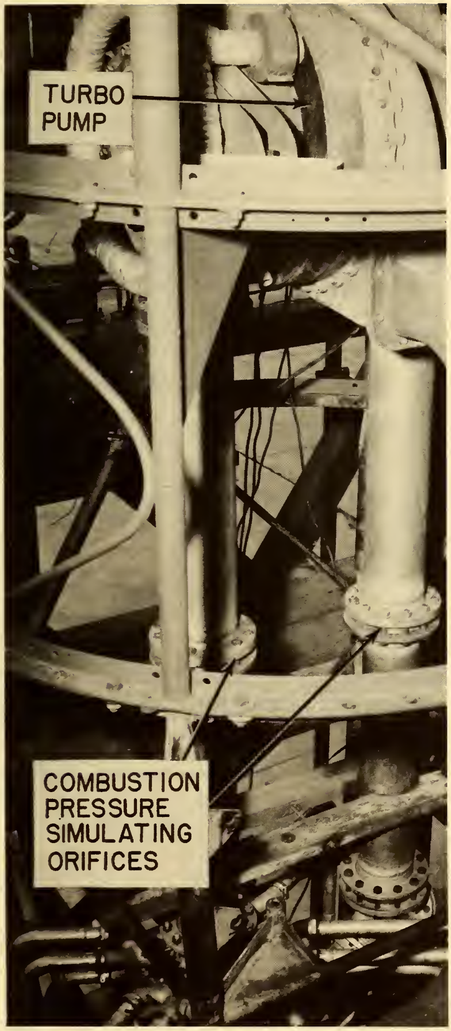


Fig. 51 Combustion-pressure Simulating Orifices and Turbopump, View A

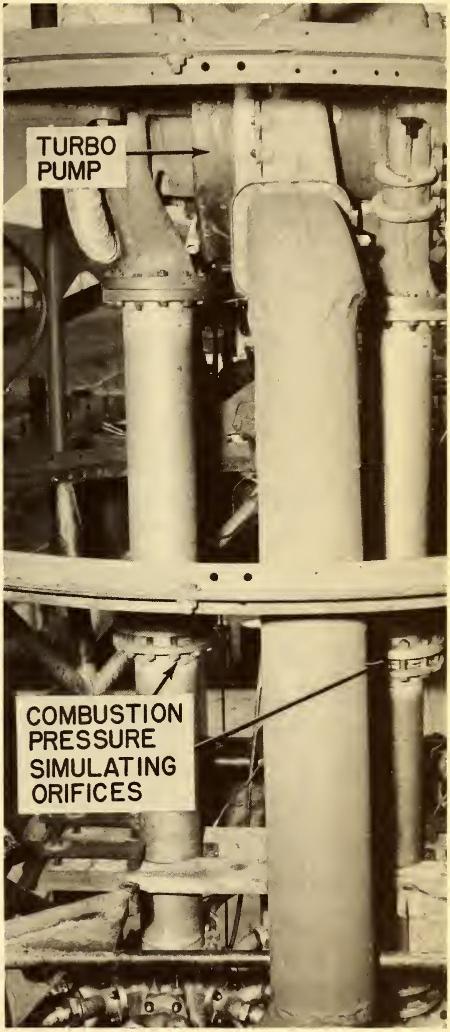


Fig. 52 Combustion-pressure Simulating Orifices and Turbopump, View B

Steam, steam exhaust and measuring lines were attached and the necessary electrical connections made. A preliminary test was run to check operation of the valves and measuring devices and to test the steam plant for leaks. The tanks were filled with filtered water, the recorders were inked and the steam plant was loaded with permanganate and peroxide. The system was then ready for the actual test.

Following the test, the excess permanganate was drained from the tank. After cooling sufficiently, the turbine was flushed by filling the peroxide tank with water and forcing the water through the turbine under air pressure. The turbine was then disassembled immediately and cleaned. The motor unit was dried immediately by means of a hot-air blower.

B.4.5 Test Data Reduction

It should be noted that mixing ratio or mixture ratio as used in this report means the ratio of alcohol flow rate to oxygen flow rate (W_f/W_o). Most current propulsion unit calculations refer to the mixture ratio as the ratio of oxygen flow rate to alcohol flow rate (W_o/W_f). However, the authors believe the W_f/W_o ratio is more appropriate to this report since all V-2 propulsion unit calculations in Germany were based on the W_f/W_o term.

To apply the calibration test data to the performance curves, it was necessary to correct the test valves to standard alcohol and oxygen flow rates.

The V-2 propulsion unit was designed for optimum performance under the following conditions:

$$\text{Mixing ratio, } \frac{\text{alcohol}}{\text{oxygen}} \quad \frac{123.5 \text{ lb per sec}}{152.5 \text{ lb per sec}} = 0.81$$

$$\text{Total flow,} \quad 276 \text{ lb per sec}$$

B.4.5.1 Gravity Corrections (due to difference in head between gage and point of measurement)

Measurement	Correction in Psi Oxygen	Correction in Psi Alcohol
Pump Inlet Pressure	-1.4	-0.5
Pump Discharge Pressure	+1.2	+1.2
Pressure after Burner Orifice	+2.2	+2.2
Injection Pressure	+3.8	+4.0
Cooling Jacket Pressure	0	+5.1

B.4.5.2 Conversion of Corrected Pressures (with water flow to standard alcohol and oxygen flow rates)

Alcohol System
$$P_C = \left(\frac{123.5}{W_W}\right)^2 \left(\frac{1}{0.86}\right) \left(P_T\right) \qquad (2)$$

where P_T = Corrected test pressure, psi
W_W = Test flow rate of water, lb per sec
0.86 = Specific gravity of 75 percent alcohol at 60^oF
123.5 = Standard alcohol flow rate, lb per sec

Oxygen System
$$P_C = \left(\frac{152.5}{W_W}\right)^2 \left(\frac{1}{1.14}\right) \left(P_T\right) \qquad (3)$$

where P_T = Corrected test pressure, psi
W_W = Test flow rate of water, lb per sec
1.14 = Specific gravity of liquid oxygen
152.5 = Standard oxygen flow rate, lb per sec

B.4.5.3 Correction of Pump Pressure to Firing Conditions (for use with performance charts)

Oxygen Pump Pressure
$$P_F = P_C + 20 - 4 = P_C + 16 \qquad (4)$$

where P_F = Pump pressure for firing, psi
P_C = Corrected pump pressure from calibration, psi
20 = Correction (tank not pressurized at calibration)
4 = Correction (added head at calibration)

Alcohol Pump Pressure $$P_F = P_C - 3 \tag{5}$$

where P_F = Pump pressure for firing, psi
P_C = Corrected pump pressure from calibration, psi
-3 = Correction (added head at calibration, psi)

B.4.5.4 Turbine Speed Correction

Since an orifice of 125 mm (open line) was used in the alcohol system, the turbine speed, corrected to standard flow, may be calculated as outlined below (provided the test results do not indicate the need for a change in the alcohol orifice).

$$S_C = \frac{S_T \times 123.5}{W_{TA} \times 0.86} \tag{6}$$

where S_C = corrected turbine speed, rpm
S_T = test turbine speed, rpm
123.5 = standard flow rate of alcohol, lb per sec
W_{TA} = test flow rate of water in alcohol system, lb per sec
0.86 = specific gravity of alcohol

If an orifice is required in the alcohol system, the turbine speed is corrected by using the ratio of the total flows in accordance with the following equation:

$$S_C = \frac{S_T \times 276.0}{W_{TA} \times 0.86 + W_{TO} \times 1.14} \tag{7}$$

where S_C = corrected turbine speed, rpm
S_T = test turbine speed, rpm
276.0 = standard total flow rate, lb per sec
W_{TA} = test flow rate of water in alcohol system, lb per sec
W_{TO} = test flow rate of water in oxygen system, lb per sec
0.86 = specific gravity of alcohol
1.14 = specific gravity of liquid oxygen

The latter method, using the ratio of total flows, is not completely accurate in that it does not take into consideration the difference in pump characteristics. However, the error is not great, being in the order of two percent.

B.4.5.5 Calculation of Orifice Size and Pressure Setting

The correct synchronizing orifice size is determined by applying the corrected test data to the pump performance curves (Fig. 53 and 54). These curves are based on experimental data and are used to simplify the calculation of orifice size. The curves are a translation of the German Work Sheet 033, except that the average pump characteristic slope has been included in the pump pressure co-ordinate. A detailed description of the curves is presented in Archive 57/13.

The calibration test is made with an orifice of 78.1 mm in the oxygen system and an orifice of 125 mm (open line) in the alcohol system. If the results of the test show the mixing ratio or the total flow to differ from the desired values by more than five percent, a second test is recommended. The limits are: 262 to 290 pounds per second for total flow and 0.77 to 0.85 for mixing ratio. These limits are set because the pump performance curves are correct only at the proper flow rates.

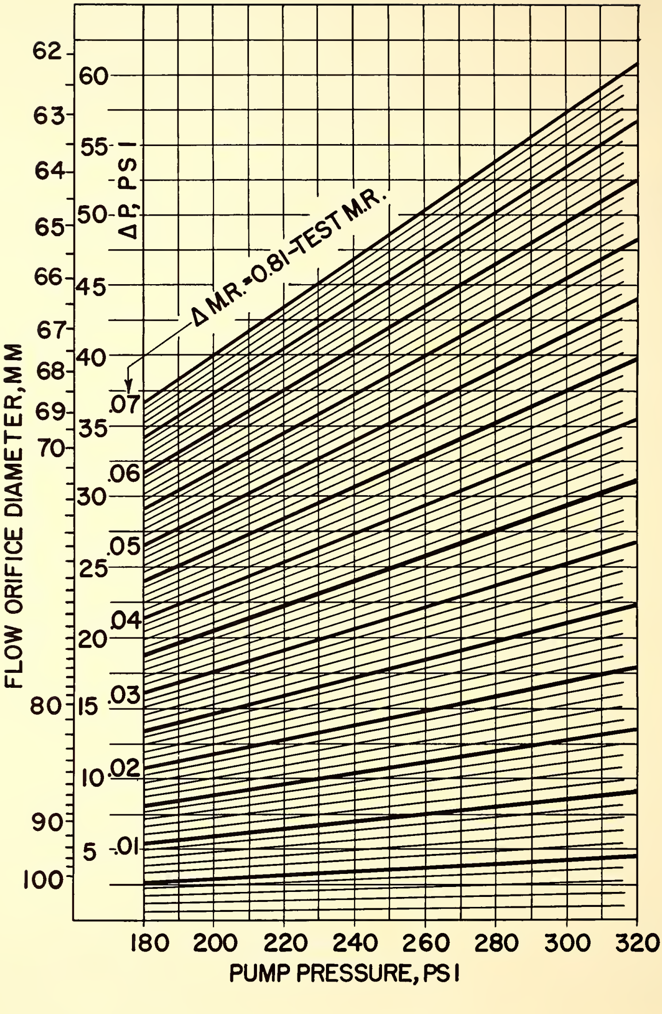


Fig. 53 Oxygen Pump Performance Curve

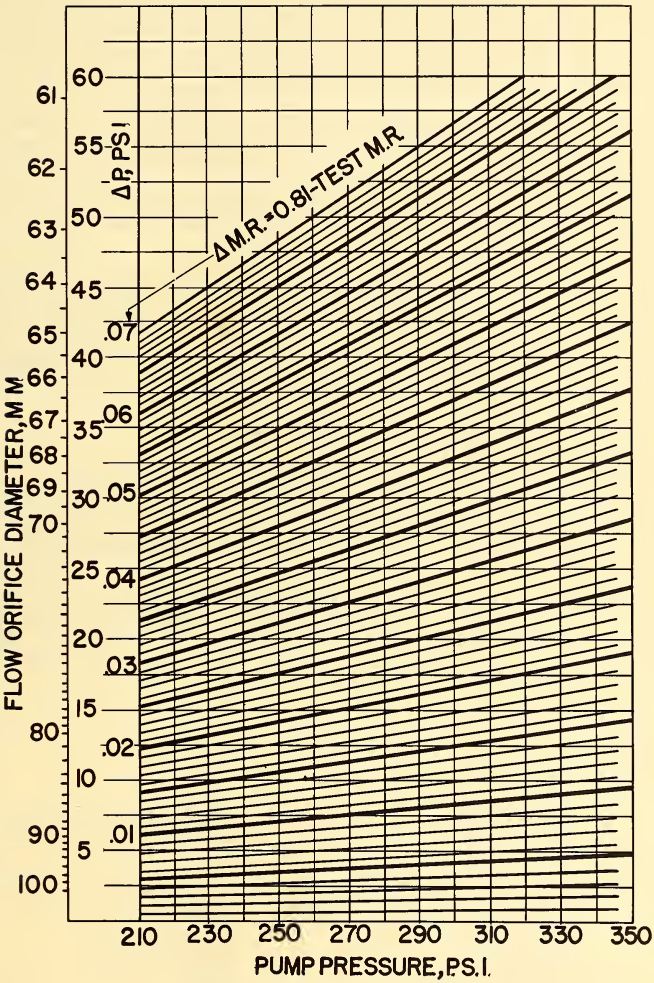


Fig. 54 Alcohol Pump Performance Curve

B.4.5.5.1 Mixing Ratio Correction (by change of orifice size)

The orifice pressure drop required to give the proper ratio is determined by applying the corrected oxygen pump pressure to the oxygen pump performance curve (Fig. 53). Proceed up the pump pressure line to the mixing ratio error line, then read directly across to the ΔP required (this ΔP is negative for ratios greater than 0.81 and positive for those less than 0.81). This is the ΔP which must be added to give the correct ratio. A ΔP of 17.7 is already present (78.1 mm orifice), hence the ΔP must be added algebraically to the 17.7 psi to give the net ΔP that must be supplied by the corrected orifice. The orifice size to give this ΔP can be read directly from the ordinate on the left.

If the net ΔP should be negative, removal of the 78.1 mm orifice would not provide complete correction. It would then be necessary to add a restriction in the alcohol side. This can be determined by locating the oxygen pump pressure and the net ΔP, on the oxygen pump performance curve (Fig. 53), and reading the new mixing ratio error at their intersection. This error is then taken to the alcohol pump performance curve (Fig. 54). On this curve the intersection of the new mixing ratio error and alcohol pump pressure is found. Directly across from this point read the ΔP and the corresponding size of orifice to be installed in the alcohol line.

The above procedure for selecting ratio orifices is based on the assumption that the test-stand orifices used to simulate combustion pressure are perfect and give exactly the correct pressure drop. In practice this was not entirely true and it was therefore necessary to transfer that pressure – drop error to the ratio orifice when calculating the size of that orifice for flight. As experience was gained, the combustion pressure simulating orifices were made more nearly correct and the above correction was thereby minimized. The changes in simulating orifice size are shown in the table of calibration data, Table II.

B.4.5.5.2 Flow Rate Correction

It was required that the mixing ratio and total flow be within five percent of the standard values during a final calibration test. However, the final run seldom gave exactly the right ratio or exactly the right flow. Therefore, it was necessary to change the flow orifice (as described above) to obtain the correct mixing ratio for flight. This change, in turn, had an effect on the flow rate. The correction for flow rate was composed of two factors: (1) correction for the change in mixing ratio and (2) correction for the original flow error.

Flow rate was adjusted by varying the setting of the pressure regulator which supplied gas to pressurize the steam plant. The corrections are given in terms of change in regulator setting, psi. The correction for mixing ratio change is shown on the pressure regulator correction curves (Fig. 55). The total flow correction is shown on the pressure regulator correction curve (Fig. 56). The use of these two curves should be evident from the two examples which follow.

B.4.5.5.3 Sample Calculations

a. Example 1

1. Standard starting values

Regulator setting	450 psi
Alcohol orifice	125 mm
Oxygen orifice	78.1 mm

2. Assumed test data

Corrected alcohol pump pressure	310.0 psi
Corrected oxygen pump pressure	255.0 psi
Alcohol flow	127.8 lb per sec
Oxygen flow	155.2 lb per sec
Total flow	283.0 lb per sec
Mixing ratio	0.823

Test No.	57-19	34	95-45	96-46	97-47	98-48	99-48	100-49
Rocket No.	BU-3	9	61	54	57	55	55	52
Date	8-3-48	5-49	9-26-50	10-18-50	12-28-50	2-21-51	2-21-51	5-15-51
Orifices Used in Place of								
Alcohol Burner (in.)	1.8305			1.8209	1.8209			
Oxygen Burner (in.)	1.9108			1.9210	1.9210			
Alcohol Flow (mm)	125		125	125	125			
Oxygen Flow (mm)	80		78.1	78.1	78.1			
Low Air Bled to (psi)	470	55	455	462	448	N.G.	458	452
Low Air Held (psi)	450	40	451	450	431		445	442
Low Air Bled – Held (psi)	20	15	4	12	17		13	10
H_2O_2 Tank (psi)	443	22	435	441	418		434	430
Steam (psi)	370	54	356	355	340		N.G.	355
Steam Temp (^oC)	N.G.	80	N.G.	367	-		350	402
Turbine Speed (rpm)	3780	40	3750	3840	3812		3816	3810
Test Flow (lb per sec)								
Alcohol – H_2O	140	7.9	146.4	146.6	139.7		142.9	140.8
Alcohol – Alcohol	120.3	7.2	125.9	126.0	120.2		122.9	121.1
O_2 – H_2O	130	3.6	132.5	129.9	129.6		128.4	129.0
O_2 – O_2	148.4	2.3	151.0	148.0	147.7		146.4	147.0
Mixing Ratio (%)	81	3.5	83	85.1	81.4		83.9	82.3
Total Flow (lb per sec)	268.7	9.5	276.9	274.1	267.9		269.4	268
Pressures (Corrected to 123.5 lb per sec								
Alcohol Pump (psi)	309	4	304.8	281.5	317		295	309
Alcohol A.O. (psi)	102.5	2	89.8	84.3	98		87	92.7
Δ P (psi)	206.5	2	215.0	197.2	219		208	216.3
Cooling Jacket (psi)	99	1	88.9	82.6	97		87.8	92.6
Injection (psi)	40.8	5	33.2	28.9	43		33.4	33
Cooling Jacket – Injection (psi)	58.2	6	55.7	53.7	54		54.4	59.6
O2 Pump (psi)	244	7	241.5	252.9	247		254	255
O_2 A.O. (psi)	44.3	5	45.5	51.0	63		53	-
Δ P (psi)	199.7	2	196.0	201.9	184		201	-
Injection (psi)	22.7	0	23.0	25.8	25		30.8	29.6
Corrected Values for Firing								
Turbine Speed (H_2O Flow)(rpm)	3878	91	3739	3867	3910		3910	3908
Low Air (psi)	465	50	460	465	465		470	470
O_2 Orifice (mm)	86	Alc.	98	80 Alc.	80.5		94 Alc.	89
Turbine Speed (Alc. Flow)(rpm)	880	28	3680	3765	3918		3835	3885

ION D

Test No.	57-19	58-20	59-21	60-22	61-23	62-24	63-25	64-26	65-27	66-28	67-29	68-30	69-31	70-32
Rocket No.	BU-3	-	42	BU-4	44	45	48	BU-5	41	46	50	BU-6	47	-
Date	8-3-48	8-6-48	8-12-48	8-18-48	8-31-48	10-6-48	12-2-48	1-20-49	2-1-49	2-8-49	3-2-49	3-16-49	3-24-49	4-27-49
Orifices Used in Place of														
Alcohol Burner (in.)	1.8305													
Oxygen Burner (in.)	1.9108					1.9310								
Alcohol Flow (mm)	125													
Oxygen Flow (mm)	80									80	125	80	80	80
Low Air Bled to (psi)	470	480	465	470	470	470	465	460	455	468	464	460	450	500
Low Air Held (psi)	450	475	480	455	453	452	408	456	435	445	428	450	445	485
Low Air Bled – Held (psi)	20	5	-15	15	17	18	57	4	20	23	36	10	5	15
H_2O_2 Tank (psi)	443	460	468	441	440	442	395	442	420	430	417	435	430	470
Steam (psi)	370	384	388	365	360	361	320	367	350	355	340	365	355	395
Steam Temp (^{o}C)	N.G.	N.G.	352	N.G.	N.G.	381	N.G.	350	352	342	350	356	350	377
Turbine Speed (rpm)	3780	4025	4020	3895	3830	3910	3600	3820	3816	3786	3838	3978	3960	4155
Test Flow (lb per sec)														
Alcohol – H_2O	140	149.8	148	144.1	146.7	147.7	134.4	149.8	141.2	141.8	142	145.7	148.9	153.4
Alcohol – Alcohol	120.3	128.8	127.2	120.8	126	127.0	115.7	128.7	121.4	121.9	122.1	125.3	128.0	132.0
O_2 – H_2O	130	136.8	139	133.2	132.2	137.9	124.3	140.4	137.3	132.5	138	139.1	140.1	145.3
O_2 – O_2	148.4	156	158.5	152	151	157.2	142.0	160.1	156.6	151.1	157.3	158.6	159.7	165.7
Mixing Ratio (%)	81	82.6	80.3	79.5	83.5	80.8	81.5	80.4	77.6	80.7	77.6	79	80.1	79.8
Total Flow (lb per sec)	268.7	284.8	285.7	272.8	277.0	284.2	267.7	288.8	278.0	283.0	279.4	283.8	278.8	297.7
Pressures (Corrected to 123.5 lb per sec Alcohol; 152.5 lb per sec O_2)														
Alcohol Pump (psi)	309	297	308.5	326.5	286	284.5	298	301	302.5	308	302	307	289.6	302.5
Alcohol A.O. (psi)	102.5	86.2	97.2	98.1	88.4	91.1	93.2	103	93.5	95	91.5	101	94.4	91.2
ΔP (psi)	206.5	210.8	211.3	228.4	197.6	193.4	204.8	198	209	213	210.5	206	195.2	211.3
Cooling Jacket (psi)	99	80.6	94.0	94.4	85.1	88.5	91.2	98.8	90	92	88	100	92	88.2
Injection (psi)	40.8	31.2	33.2	37.2	34.7	30.1	28.9	36.8	28	32	35.2	31	32	27.2
Cooling Jacket – Injection (psi)	58.2	49.4	60.8	57.2	50.4	59.4	62.3	62.1	62	60	52.8	69	60	61.0
O_2 Pump (psi)	244	245	239	248	239.6	234.4	234	232	216	241	218	230	214	229.5
O_2 A.O. (psi)	44.3	41.7	40.4	42.4	40.6	47.1	41.5	44.2	-	49	-	43	40.4	44.4
ΔP (psi)	199.7	203.3	198.6	205.6	199.0	187.3	192.5	187.8	-	192	-	187	173.6	185.1
Injection (psi)	22.7	20.6	20.4	20.0	20.8	24.4	18.4	23.1	-	25.5	21.9	22	21.2	22.7
Corrected Values for Firing														
Turbine Speed (H_2O Flow)(rpm)	3878	3896	3884	3941	3816	3787	3711	3650	3789	3692	3791	3867	3787	3852
Low Air (psi)	465	450	464	470	440	440	460	460	470	455	460	467	448	-
O_2 Orifice (mm)	86	83	73	69	90	83	76	72	65.5	72.5	71.5	68	76	-
Turbine Speed (Alc. Flow)(rpm)	880	3857	3903	3982	3754	3802	3843	3666	3882	3836	3882	3921	3821	3887

Test No.	71-32	72-32	79-33	80-34	81-35	82-36	83-37	84-37	85-37	86-38	87-39	88-40
Rocket No.	-	-	32	49	56	31	-	-	-	53	BU-7	BU-8
Date	4-27-49	4-28-49	8-10-49	8-15-49	9-21-49	11-15-49	11-29-49	11-30-49	11-30-49	12-8-49	12-19-49	1-10-50
Orifices Used in Place of												
Alcohol Burner (in.)			1.8209									
Oxygen Burner (in.)			1.9210									
Alcohol Flow (mm)												
Oxygen Flow (mm)	70	70	78.1				78.1	67	87	78.1		
Low Air Bled to (psi)	460	454	455	455	440	443	446	464	464	453	450	453
Low Air Held (psi)	447	444	437	440	433	436	438	454	455	445	443	446
Low Air Bled – Held (psi)	13	10	18	15	7	7	8	10	9	8	7	7
H_2O_2 Tank (psi)	435	435	420	422	420	424	428	442	443	431	430	430
Steam (psi)	360	363	350	354	348	349	350	-	366	354	355	355
Steam Temp (^{o}C)	377	380	380	380	380	360	392	383	392	385	385	370
Turbine Speed (rpm)	3980	3980	3996	3840	3850	3816	3881	3970	3979	3915	3850	3816
Test Flow (lb per sec)												
Alcohol – H_2O	148.3	147.1	144	147.9	147.6	141.8	138.0	141.2	142.0	146.0	141.3	142.1
Alcohol – Alcohol	127.5	126.5	124	127.2	126.9	122.0	118.7	122.4	122.1	125.6	121.5	122.2
O_2 – H_2O	135.6	135.8	136.5	133.6	132.1	135.1	134.1	129.6	129.8	133.7	129.0	130.7
O_2 – O_2	154.7	154.8	155.5	152.3	150.8	154.0	152.9	147.7	148.0	152.4	147.1	149.0
Mixing Ratio (%)	82.5	81.8	79.6	83.5	84.3	79.2	78	82.2	82.5	82.4	82.6	82.0
Total Flow (lb per sec)	282.2	281.3	279.7	279.5	277.5	276.0	271.0	269.1	270.1	278.0	268.6	271.2
Pressures (Corrected to 123.5 lb per sec Alcohol; 152.5 lb per sec O_2)												
Alcohol Pump (psi)	295.5	299.3	319	304	296	333	330	-	326	291.5	318.4	306.6
Alcohol A.O. (psi)	92.1	90.2	96.4	92	86.3	116	112	108.8	105	91.5	99.7	100.3
ΔP (psi)	203.4	209.1	222.6	212	209.7	217	218	-	221	200	218.7	206.3
Cooling Jacket (psi)	88	86.9	93.8	81	84.7	113	112	108.7	104	93.0	101.4	99.3
Injection (psi)	27.8	27.5	29.4	35	32.6	48	48.8	45.8	41	33.6	47.6	35.6
Cooling Jacket – Injection (psi)	60.2	59.4	64.4	58	52.1	65	63.2	62.9	63	59.4	53.8	63.7
O_2 Pump (psi)	250	246.4	243	237	240	234	244	276	276	248	252.6	246.6
O_2 A.O. (psi)	63.3	61.6	46.9	45	45	49	54.5	77.7	78	53	51.7	49.0
ΔP (psi)	186.7	184.8	196.1	192	195	185	189.5	198	198	185	200.8	197.6
Injection (psi)	21.7	20.9	20.7	20	18.6	27	32.5	32.4	31	30	27.1	25.9
Corrected Values for Firing												
Turbine Speed (H_2O Flow)(rpm)	3892	3905	3943	3791	3829	3816	3953	4072	4066	3887	3956	3750
Low Air (psi)	-	-	456	450	440	470	485	480	480	455	470	470
O_2 Orifice (mm)	-	-	79	81 Alc.	96 Alc.	72	68	71.3	73	96	100	87
Turbine Speed (Alc. Flow)(rpm)	3855	3886	3980	3728	3747	3863	4038	4039	4025	3850	3913	3776

Test No.	89-41	90-42	91-43	92-44	93-44	94-44	95-45	96-46	97-47	98-48	99-48	100-49
Rocket No.	51	-	-	-	-	-	61	54	57	55	55	52
Date	2-13-50	7-8-50	7-11-50	7-19-50		7-21-50	9-26-50	10-18-50	12-28-50	2-21-51	2-21-51	5-15-51
Orifices Used in Place of												
Alcohol Burner (in.)								1.8209	1.8209			
Oxygen Burner (in.)								1.9210	1.9210			
Alcohol Flow (mm)						78.1	125	125	125			
Oxygen Flow (mm)						125	78.1	78.1	78.1			
Low Air Bled to (psi)	454	447	460	460	N.G.	453	455	462	448	N.G.	458	452
Low Air Held (psi)	445	438	452	450		443	451	450	431		445	442
Low Air Bled – Held (psi)	9	9	8	10		10	4	12	17		13	10
H_2O_2 Tank (psi)	432	422	435	432		430	435	441	418		434	430
Steam (psi)	357	346	360	356		351	356	355	340		N.G.	355
Steam Temp (^{o}C)	400	N.G.	358	N.G.		370	N.G.	387	-		350	402
Turbine Speed (rpm)	3920	3940	3866	3846		3820	3750	3840	3812		3816	3810
Test Flow (lb per sec)												
Alcohol – H_2O	141.2	141.3	143.8	145.9		140.1	146.4	146.6	139.7		142.9	140.8
Alcohol – Alcohol	121.4	121.5	123.7	125.5		120.5	125.9	126.0	120.2		122.9	121.1
O_2 – H_2O	131.7	129.8	134.5	128.9		132.7	132.5	129.9	129.6		128.4	128.0
O_2 – O_2	150.1	148.1	153.3	147.0		151.3	151.0	148.0	147.7		146.4	147.0
Mixing Ratio (%)	80.9	82.1	80.7	85.4		79.6	83	85.1	81.4		83.9	82.3
Total Flow (lb per sec)	271.5	269.5	277	272.5		271.8	276.9	274.1	267.9		269.4	268
Pressures (Corrected to 123.5 lb per sec Alcohol; 152.5 lb per sec O_2)												
Alcohol Pump (psi)	317.9	303.7	302	290.7		312.5	304.8	281.5	317		295	309
Alcohol A.O. (psi)	103.4	104.3	96.5	93.1		111.8	89.8	84.3	98		87	92.7
ΔP (psi)	214.5	199.4	205.5	197.6		200.7	215.0	197.2	219		208	216.3
Cooling Jacket (psi)	103.3	105.1	95.5	83.0		93.7	88.8	82.6	97		87.8	92.6
Injection (psi)	40.5	40.2	32.7	35.3		36.1	33.2	28.9	43		33.4	33
Cooling Jacket – Injection (psi)	62.8	69.9	62.8	57.7		57.6	55.7	53.7	54		54.4	59.6
O_2 Pump (psi)	252.8	253.1	238.7	254.9		233.4	241.5	252.9	247		254	255
O_2 A.O. (psi)	55.7	52.9	54.1	56.8		36.2	45.5	51.0	63		53	-
ΔP (psi)	197.1	200.2	184.6	198.1		197.1	196.0	201.9	184		201	-
Injection (psi)	33.4	31.2	33.7	36.0		36.3	23.0	25.8	25		30.8	28.6
Corrected Values for Firing												
Turbine Speed (H_2O Flow)(rpm)	3985	4035	3852	3895		3879	3739	3867	3910		3910	3908
Low Air (psi)	475	465	452	445		446	460	465	465		470	470
O_2 Orifice (mm)	78	86	78	78 Alc.		88 Alc.	98	80 Alc.	80.5		94 Alc.	89
Turbine Speed (Alc. Flow)(rpm)	3988	4005	3860	3785		3915	3680	3765	3918		3835	3885

TABLE II

V-2 PROPULSION SYSTEM CALIBRATION DATA

3. Mixing Ratio Correction

$$\Delta M.R. = 0.81 - 0.823 = -0.013$$

Going to the oxygen pump performance curve (Fig. 53) and following the pump pressure line of 255 psi to the ΔM.R. line of 0.013 gives a pressure drop (ΔP) of - 9.6 psi. Adding this to the orifice (78.1 mm) drop of 17.7 gives a net ΔP of 8.1 psi and a required orifice size of 88 mm.

Total Flow Correction

To obtain the change in pressure regulator setting required by the above change in orifice, use the pressure regulator correction curve (Fig. 55). On the curve for "Orifice in Oxygen Line," (Fig. 55, bottom) locate the point for a ratio of 0.823 and directly across to the left find the value of - 7.5 psi.

To obtain the change in pressure regulator setting required by the excess flow shown in the test data (283 vs 276 lb per sec), go to the pressure regulator correction curve for total flow error (Fig. 56). Locate the 283 lb per sec point on the curve and directly across to the left find the value of - 26 psi.

The regulator setting for flight is 450 - 7.5 - 26.0 = 416.5 psi.

b. Example 2

1. Standard starting values

Regulator setting	450 psi
Alcohol orifice	125 mm
Oxygen orifice	78.1 mm

2. Assumed test data

Corrected alcohol pump pressure	295.0 psi
Corrected oxygen pump pressure	255.0 psi
Alcohol flow	124.1 lb per sec
Oxygen flow	147.9 lb per sec
Total flow	272.0 lb per sec
Mixing ratio	0.839

3. Mixing Ratio Correction

$$\Delta M.R. = 0.81 = 0.839 = - 0.029$$

Going to the oxygen pump performance curve (Fig. 53) and following the pump pressure line of 255 psi to the ΔM.R. line of 0.029 gives a pressure drop (ΔP) of 21 psi (this value is negative when ΔM.R. is negative). Adding this to the installed orifice drop of 17.7 psi gives a net ΔP of - 3.3 psi. Since this value is negative, the remaining correction must be made on the alcohol side. Transferring from one performance curve to the other (oxygen, Fig. 53 to alcohol, Fig. 54) must be accomplished on the basis of ΔM.R. only. The 3.3 psi on the oxygen curve gives a ΔM.R. of 0.0045, which must be corrected on the alcohol side. From the alcohol pump performance curve (Fig. 54), a pump pressure of 295 psi and a ΔM.R. of 0.0045 gives a ΔP of 3.6 psi, which requires an orifice of 97 mm in the alcohol line.

4. Total Flow Correction

To obtain the change in pressure regulator setting required by this change in orifices, it is necessary to use both sections of the pressure regulator curve (for change in mixing ratio, Fig. 55).

From the curve for "Orifice in Oxygen Line," (Fig. 55, bottom) read the correction corresponding to that portion of the ratio correction accomplished by removing the oxygen orifice. This is 0.029 - 0.0045 = 0.0245. Add this value to the desired ratio of 0.81 to obtain 0.8345, the value to be used with the "Oxygen" curve (Fig. 55, bottom). From that curve the correction is read as - 14 psi.

From the curve for "Orifice in Alcohol Line," (Fig. 55, top) read the value corresponding to that portion of the ratio correction accomplished by the addition of the orifice in the alcohol line. The mixing ratio used in this case is the desired ratio plus that portion of the error which was not corrected by removal of the oxygen orifice. This is 0.81 + 0.0045 = 0.8145. From the curve (Fig. 55, top) the corresponding correction is read as + 1.3 psi.

The total pressure regulator correction for the change in mixing ratio is then the algebraic sum of the above, or: -14.0 + 1.3 = - 12.7 psi.

From the pressure regulator curve for total flow error (Fig. 56), read the correction required by the low flow as shown in the test data (272 lb per sec). This correction is + 13 psi.

The final pressure regulator setting for firing is then:

Initial regulator setting	450 psi
Correction for change in mixing ratio	-12.7 psi
Correction for low test flow	+13.0 psi
Regulator setting for firing	450.3 psi

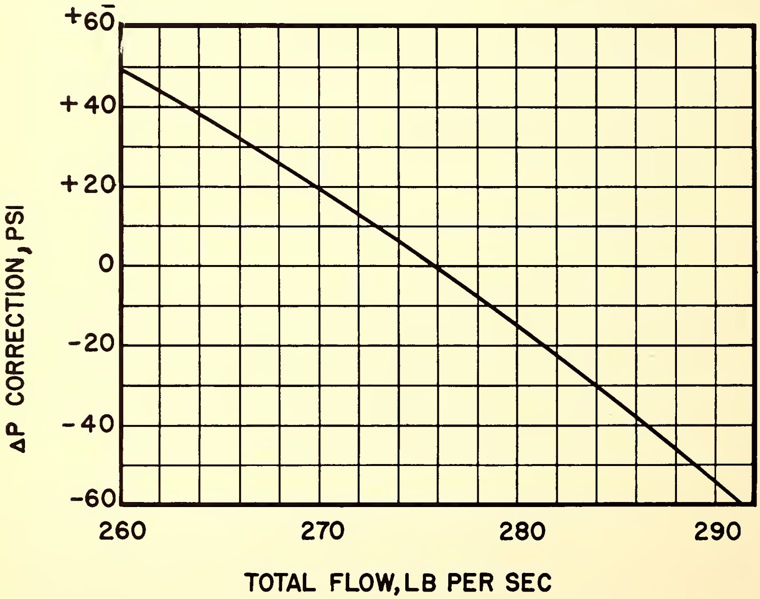


Fig. 56 Pressure Regulator Correction Curve for Total Flow Error

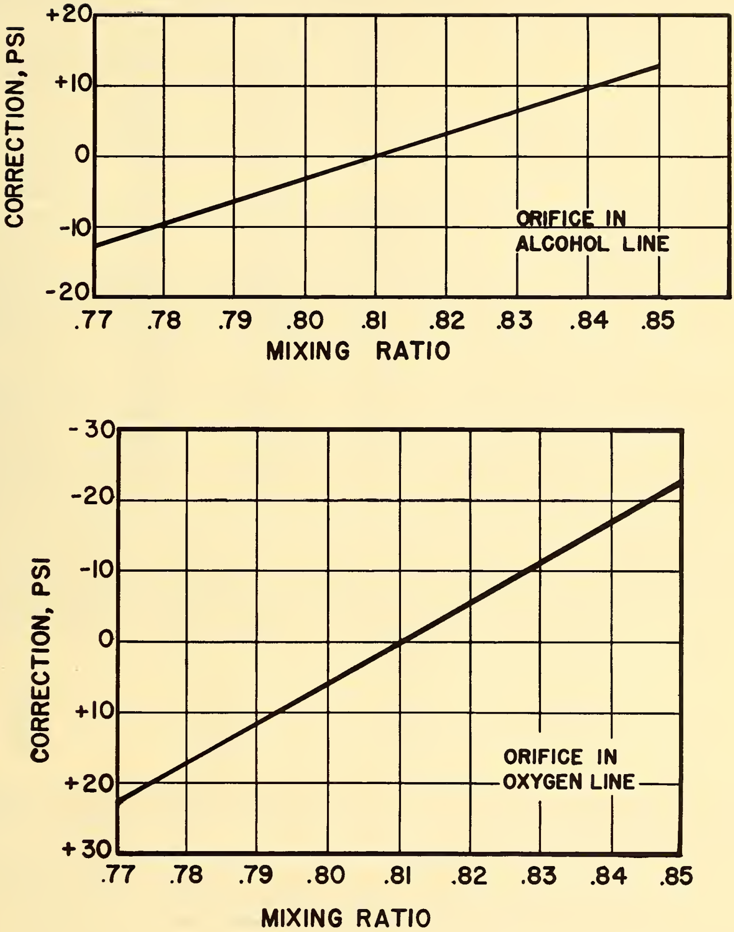


Fig. 55 Pressure Regulator Correction Curves for Mixing Ratio Change

B.5 CALIBRATION AND FLIGHT DATA

B.5.1 Average Values from Calibration Data

The following table gives average, maximum and minimum values obtained by 19 calibration runs with final calibration equipment and procedures. In compiling these figures, test data from runs 79-33 through 100-49 (omitting runs 84-37, 85-37 and 94-44) were used. Complete data on these test runs will be found in Table II.

MEASUREMENT	UNITS	MINIMUM	AVERAGE	MAXIMUM
Air pressure (bled)	psi	440	452	462
Air pressure (held)	psi	431	442	452
Tank pressure – hydrogen peroxide	psi	418	428	441
Steam pressure	psi	340	353	360
Steam temperature	^{o}C	350	378	402
Turbine speed	rpm	3750	3857	3996
Alcohol flow (water)	lb per sec	138.0	143.4	147.9
Equivalent flow using alcohol	lb per sec	118.7	123.3	127.2
Oxygen system flow using water	lb per sec	128.4	131.7	136.5
Equivalent flow using oxygen	lb per sec	146.4	150.2	155.5
Mixing ratio		0.78	0.821	0.854
Alcohol pump outlet	psi	281.5	307.1	333.0
Alcohol pressure below combustion orifice	psi	84.3	96.7	116.0
Pressure drop across combustion orifice	psi	197.2	210.4	222.6
Alcohol pressure at burner inlet	psi	82.6	96.1	113.0
Alcohol pressure before injection nozzles	psi	28.9	37.1	48.8
Pressure drop across cooling jacket	psi	52.1	59.3	69.9
Oxygen pump outlet pressure	psi	234.0	246.8	255.0
Oxygen pressure below combustion orifice	psi	45.0	51.6	63.0
Pressure drop across combustion orifice	psi	184.0	194.6	201.9
Oxygen pressure before injection nozzles	psi	18.6	27.7	36.0

B.5.2 Static Firing Data

Three propulsion units were tested by static firing after the normal "cold" calibration had been made. The total flow and the mixing ratio, as determined by the static firings, is tabulated below:

TEST NO.	DATE	CALIBRATION TEST NO.	TOTAL FLOW LB PER SEC	MIXING RATIO
1	10/21/48	58-20	290	0.791
2	10/25/48	58-20	272	0.802
3	7/19/50	91-43	288	0.790
4	7/29/50	94-44	292	0.778

Tests 1 and 2 were made on the same propulsion unit. The ratio orifices used in test 3 were the same as those used in the "cold" calibration of that unit. The mixing ratio shown by the "cold" calibration was 0.807, which indicated that no change of orifice was required.

Although the above data show some departure from the intended flow and ratio, the errors are not unreasonable when the accuracy of the measurements is considered. Flow rate measurements during static firings were not completely satisfactory, particularly in the oxygen system. It is believed that appreciable errors were introduced by the low temperature (-183^{o}C) of the liquid oxygen.

B.5.3 Flight Data

Flight data pertinent to this section is included in Table III, p. 116.

B.6 SPECIAL V-2 PROPULSION UNIT TESTS

B.6.1 Introduction

Special tests were run on the V-2 propulsion unit to aid in determining the cause of rocket motor failures in flight. By observing the effect of controlled malfunctioning of the propulsion unit, it is possible that the accuracy of analyzing rocket motor failures in flight may be greatly increased. These tests were arranged to determine the effect of the actions noted below on rocket motor performance:

a. Applying control pressure to the oxygen main valve,

b. Applying control pressure to the alcohol main valve,

c. Applying control pressure to both the alcohol and oxygen main valves,

d. Closing the preliminary alcohol valve.

B.6.2 Test Procedure

a. All tests were run on the calibration stand with the following changes from normal calibration procedure.

1. Combustion pressure for the alcohol system was simulated by four 0.952-inch diameter orifices machined in a sleeve inserted in the combustion chamber dome (around the main alcohol valve).

2. Combustion pressure for the oxygen system was simulated by eighteen 0.4823-inch diameter orifices located in the normal oxygen injection nozzle position. The oxygen injection nozzles were mounted on a seven-inch pipe extension.

3. Conventional main alcohol and main oxygen valves were used in place of the special valves normally used for calibration (special valves are necessary for calibration because the combustion pressure is simulated by an orifice in the pump discharge of the alcohol and oxygen system).

4. The alcohol and oxygen main valve positions were recorded on a photoelectric recorder by means of a slide wire potentiometer mechanically connected to the valves.

5. Provisions were made in tests 2 and 3 (Tables IV, V and VI) to measure the alcohol by-pass flow. This was accomplished by connecting the by-pass line to a separate tank and weighing the water. The assumption was made that the gain by a lower by-pass discharge pressure would be approximately offset by a reduction in pump inlet pressure. Data from tests 2 and 6 and tests 3 and 4 indicate the assumption was not valid.

6. The test method was the same as that used in calibration runs with control pressure applied to the alcohol and oxygen main valves (under valve control pressure) for the time intervals indicated.

b. Discrepancies between test and flight conditions and the effect on test results are outlined below.

1. Water used in place of alcohol and oxygen:

(a) Under normal operating procedures the effect will be negligible because the reduction in horsepower required by the oxygen pump is offset by the increase in horsepower required by the alcohol pump.

(b) When control pressure is applied to the main valves, the amount of valve opening depends solely on the pump discharge pressure and not on the volume flow. Therefore, under flight condition the oxygen valve would tend to close less and the alcohol valve more. This would make slight changes in test results.

2. Combustion pressure simulated by orifices:

(a) Reduction of flow in one system (by applying control pressure to the main valve) will not reduce the combustion pressure in the other system as it would in flight. This means that in flight there would be a greater increase in turbine speed with corresponding changes in flows and pressures when the oxygen valve is operated. In addition, turbine speed would probably increase (instead of decrease as shown by test data) when the alcohol valve is operated.

TABLE III

V-2 FLIGHT DATA

Rocket (No.)	Cal (No.)	Date (M/D/Y)	Wait Time (min)	Empty Weight (lb)	Aic Weight (lb)	Lox Weight (ib)	Launch Weight (lb)	From Calibration: Low Air (psi)	From Calibration: Turb Speed (rpm)	From Calibration: Aic Orf (mm)	From Calibration: Lox Orf (mm)	From Telemetry: Low Air (psi)	From Telemetry: Turb Speed (rpm)	From Telemetry: Comb Press (psi)	Burn Time (sec)	Prog (seq)	Vei (fps)	Alt (miles)	Range (miles)	Cut-Off
1	-	3-15-46	-	-	-	-	-	-	-	-	-	-	-	-	57.0	-	-	-	-	Desk
2	-	4-16-46	-	8530	-	-	-	-	-	-	-	-	-	-	19.0	-	-	5	0	Radio
3	-	5-10-46	-	8190	-	-	App. 27850	-	-	-	-	-	-	-	59.0	-	-	70	31.0	INT
4	-	5-29-46	-	8696	-	-	App. 28400	-	-	-	-	-	-	-	60.2/63.1	9.9	4100	70	37.6	INT
5	-	6-13-46	160	9286	-	-	28396	-	-	-	-	-	4840	225	58.5/61.2	9.3	4220	73	40	INT
6	-	6-28-46	90	9807	8547	10230	29146	-	-	-	-	-	-	-	66.8	11.4	4075	67	41.0	B/O
7	-	7-9-46	62	8977	8723	9636	27850	-	-	-	-	-	-	200	61.0	12.4	4680	83	61.0	TS
8	-	7-19-46	75	9167	-	-	28840	-	-	-	-	-	4600	184	28.5	-	1310	3	0.5	EXP
9	-	7-30-46	95	8562	-	-	28000	-	-	-	-	-	-	-	68.6	11.8	5130	104	68.0	B/O
10	-	8-15-46	60	9012	-	-	28694	-	-	-	-	-	4025	152	18.5	-	662	2	0.7	Radio
11	-	8-22-46	100	9152	-	-	27220	-	-	-	-	-	3775	160	6.5	-	-	0	0	Radio
12	-	10-10-46	65	9164	-	-	28760	-	-	-	-	-	-	-	67.7	2.0	5350	102	12.0	B/O
13	-	10-24-46	60	9070	-	-	29000	-	-	-	-	-	-	-	59.8	4.7	3990	65	17.0	B/O
14	-	11-7-46	-	8684	-	-	28000	-	-	-	-	-	-	-	31.0	-	-	0	5.0_s	Radio
15	-	11-21-46	45	8885	-	-	28670	-	-	-	-	-	3905	-	62.5	3.5	3876	63	12.6	B/O
16	-	12-5-46	60	9050	-	-	28782	-	-	-	-	-	3750	190	69.0	21.0	5204	104	-	B/O
17	-	12-17-46	72	8797	8800	10370	28962	-	-	-	-	-	4010	210	69.6	3.0	5402	116	21	B/O
18	-	1-10-47	45	9434	8800	10550	29100	-	-	-	-	-	1100	195	60	6.0	4400	72	25.0	B/O
19	-	1-23-47	140	9140	-	-	28355	-	-	-	-	-	-	-	59	-	2300	31	10.3	B/O
20	-	2-20-47	90	9390	8800	9850	28455	-	-	-	-	-	-	220	58.0	-	4062	68	11.0	B/O
21	-	3-7-47	63	9182	8800	10450	28847	-	-	-	-	-	4600	-	63.0	-	5120	100	35.0	B/O
22	-	4-1-47	116	8800	8815	10080	28095	-	-	-	-	-	3600	210	57.0/60.5	5.6	4457	80	24.0	TS
23	-	4-8-47	98	8840	8815	10232	27460	-	-	-	-	-	-	-	57.0/60.0	5.2	3825	64	19.0	TS
24	-	4-17-47	82	9061	8800	10450	28726	-	-	-	-	-	-	-	66.0	8.5	4710	87	45.0	B/O
26	-	5-15-47	60	9827	8800	10450	29492	-	-	-	-	-	-	-	63.5	9.6	4696	76	35.0	B/O
29	-	7-10-47	-	9522	8800	10450	29187	-	-	-	-	-	3030	225	32.0	-	1450	10	1.4	Radio
30	-	7-29-47	-	8533	8800	10450	28198	-	-	-	-	-	-	-	62.5	-	4962	99	1.0_s	B/O
27	-	10-9-47	75	9107	8800	10450	28772	-	-	-	-	-	-	-	62.5	-	4987	97	28.0	TS
SPEC.	8	11-20-47	90	9249	8800	10200	28914	480	-	125	75.5	-	3600	215	39.0	-	1632	13	1.5	Fault
28	10	12-8-47	60	9493	8800	10450	29158	512	-	125	61.9	538	3000	254	61.5	7.2	3939	65	28.0	B/O
34	11	1-22-48	88	9548	8810	10800	29000	440	-	125	84	510	4200	142	67.0	7.0	4985	99	48.0	B/O
36	3	2-6-48	102	8789	8810	10800	28814	440	3750	125	80.6	410	-	188	65.8	-	4300	70	1.4_s	B/O
39	6	3-19-48	90	9659	8800	10350	29224	475	-	125	76.5	460	3950	220	25.0	-	720	3.0	1.0_s	-
25	9	4-2-48	177	9742	8800	10141	29100	474	-	80	71.5	-	-	212	69.5	9.1	4682	89	48.0	B/O
38	12	4-19-48	219	9169	8800	9900	28834	458	3680	125	95	-	3850	205	57.0	-	3679	35	32.0	Radio

TABLE III (CONT'D)

V-2 FLIGHT DATA

Rocket	Cal	Date	Wait Time	Empty Weight	Alc Weight	Lox Weight	Launch Weight	From Calibration				From Telemetry			Burn Time	Prog	Vel	Alt	Range	Cut-Off
								Low Air	Turb Speed	Alc Orf	Lox Orf	Low Air	Turb Speed	Comb Press						
(No.)	(No.)	(M/D/Y)	(min)	(lb)	(lb)	(lb)	(lb)	(psi)	(rpm)	(mm)	(mm)	(psi)	(rpm)	(psi)	(sec)	(seq)	(fps)	(miles)	(miles)	
BU-1	13	5-13-48	139	8573	8800	10000	27938	444	3600	125	90	-	3600	180	64.5/67.9	-	4010	70	34.0	INT
35	7	5-27-48	75	10411	8800	10450	30076	470	-	80	84	510	-	-	82.4/65.5	7.8	4600	87	41.0	TS
37	15	6-11-48	187	10181	8800	10450	29826	474	3650	125	92	440	3500	180	57.3	-	3013	39	17.0	Fault
40	16	7-28-48	81	9942	8800	10350	29807	480	3650	125	72	490	4000	235	60.8	7.1	3770	80	23.0	B/O
43	18	8-5-48	79	8993	8800	10450	28658	467	3700	125	125	450	-	220	65.5	8.6	5200	104	53.0	B/O
BU-2	14	8-19-48	95	8082	8800	10150	27447	465	-	125	76	473	3840	213	33.8	-	1250	8	0.9	Fault
33	17	9-2-48	145	8422	8800	10400	28037	476	3900	125	78.5	475	3650	-	63.0/65.4	6.7	4822	94	40.0	TS
BU-3	19	9-30-48	83	8052	8800	10150	27417	465	3878	125	86	473	3570	222	56.5/70.2	4.3	4625	93	21.0	INT
BU-4	22	11-1-48	97	8105	8800	10150	27470	470	3941	125	69	-	3750	-	28.5	-	1280	3	1.0_s	EXP
44	23	11-18-48	118	8858	8800	10300	28523	440	3816	125	90	-	-	-	65.5	5.1	4760	90	29.0	B/O
42	21	12-9-48	104	8234	8800	10150	28106	485	3884	125	73	452	3600	205	60.6/64.0	8.5	4030	67	25.0	TS
45	24	1-28-49	40	9537	8800	10700	29450	440	3797	125	83	420	3850	240	56.5	5.1	2925	37	10.5	Radio
48	25	2-17-49	82	9652	8800	10350	29217	460	3711	125	76	480	4100	220	83.5	8.2	4400	79	37.0	B/O
BU-5	26	2-24-49	76	8732	8800	10350	28297	480	3650	125	72	445	-	200	61.0/64.5	6.7	3800	63	21.5	INT
41	27	3-21-49	68	9971	8800	10450	29636	470	3789	125	65.5	-	-	-	65.5	6.8	4460	80	32.4	B/O
50	29	4-11-49	100	9530	8800	10228	28973	450	3791	125	71.5	500	3850	-	62.5	6.4	3450	53	20	TS
BU-6	30	4-21-49	72	8651	8500	10355	27938	467	3867	125	68	-	3650	234	48.0	-	2660	31	0.4	Fault
46	28	5-5-49	68	9200	8680	10630	28940	455	3692	125	72.5	460	3750	210	25.8	-	1050	5	1.4	Fault
47	31	6-14-49	80	10575	8838	10584	30171	455	3797	125	71	445	3900	205	67.3	7.0	4407	83	37.0	B/O
32	33	9-16-49	116	9996	8700	9995	28839	456	3943	125	79	-	2750	170	24.7	-	783	3	0.5	EXP
49	34	9-29-49	72	9278	8740	10475	28911	450	3791	81	125	455	3840	225	85.5	8.1	4960	94	43.5	B/O
58	35	11-18-49	173	10414	8750	9725	29315	440	3829	96	125	545	3800	242	66.4	8.0	4250	77	32.0	TS
31	36	12-8-49	99	10211	8774	10290	29695	470	3816	125	72	475	3900	225	65.0	8.4	4430	79	37.8	B/O
53	38	2-17-50	67	9900	8941	11045	29433	455	3887	125	96	475	4010	226	65.0	7.0	4825	92	40.5	B/O
BU-8	40	7-24-50	68	8575	8552	10385	27937	470	3750	125	87	-	-	-	-	-	-	-	-	INT
BU-7	39	7-29-50	35	8665	8565	10590	28245	470	3956	125	100	-	-	-	-	-	-	-	-	INT
51	41	8-31-50	59	10683	8573	10440	30183	470	3988	125	78	510	4103	238	64.9	7.5	4660	85	36.1	B/O
61	45	10-26-50	69	8807	8652	10296	28180	460	3680	125	98	-	-	-	49.7	-	3153	-	15.4	EXP
54	46	1-18-51	34	9296	8812	10694	29227	465	3867	80	125	-	3978	-	44.0	-	300	1	0.5	B/O
57	47	3-8-51	60	10407	8687	10548	30067	465	3910	125	80.5	-	3900	270	18.5	-	642	2	0.2_s	EXP
55	48	6-14-51	56	9192	8687	10491	28795	470	3910	94	125	-	-	-	-	-	0	0	0	EXP
52	49	8-28-51	66	9781	8800	10415	29431	470	3900	125	89	-	3918	-	22.0	-	825	4	0.4	Radio

In Cut-Off column, INT means integrator, TS time switch, B/O burnout and EXP explosion.

TABLE IV

DATA FROM SPECIAL TESTS ON
V-2 PROPULSION UNIT

Test No.	S-1		S-2		S-3			S-4				S-5		S-6	
Valve Control Pressure	Normal	Oxy. On	Normal	Alc. On	Normal	Oxy. On	O_2 & Alc. On	Normal	O_2 & Alc. On Siml.	Normal	Prel. Alc. On	Normal	Oxy. On	Normal	Alc. On
Time (sec)	0-20	21-45	0-20	21-45	0-20	21-25	26-45	0-10	11-25	26-30	31-38	0-20	21-46	0-20	21-33
High Air (psi)	2050	2000	2300	2200	2500	2400	-	2150	2050	-	-	2200	2100	2850	2750
Low Air (psi)	440	440	440	440	440	441	442	442	442	442	442	445	445	502	503
H_2O_2 Tank (psi)	428	430	428	430	428	429	430	428	430	430	430	430	432	482	485
Steam (psi)	360	360	360	360	360	360	360	360	360	360	360	360	369	395	395
(Ind) Turbine Speed (rpm)	3900	4150	3900	3950	3850	3975	4050	NG	NG	NG	NG	3750	3900	3750	3575
(Counter) Turb. Speed (rpm)	3880	4170	3840	3930	3810	3960	4092	3790	3960	3840	-	3822	4002	3720	3600
Oxygen															
Pump Inlet (psi)	2.7	3.8	2.5	1.3	3.0	4.55	4.3	3.6	5.3	2.5	2.0	3.2	4.5	3.1	2.6
Pump (psi)	200	265	197	202	194	250	260	197	246	197	278	197	253	190	174
Before Orifice (psi)	180	NG	176	180	175	37	50	177	30	177	210+	177	87	168	156
Injection (psi)	16.0	4.0	12.5	11.0	12.0	2.5	2.5	21.4	2.0	11.5	12.0	7.0	2.1	7.7	8.1
Δ P-B.O. (Inj. psi)	164.0	-	163.5	169.0	163.0	34.5	47.5	155.6	28.0	165.5	198+	170.0	34.9	160.3	147.9
Flow (lb/sec H_2O)	141.0	81.6	141.7	144.2	141.8	74.8	78.9	NG	62.5	142.6	-	140.7	69.8	140.7	134.1
Flow (lb/sec O_2)	161.0	93.1	161.5	164.3	161.7	85.3	90.0	NG	71.3	162.8	-	160.2	79.6	160.4	152.9
Valve Pressure (psi)	0	440	0	0	0	440	442	0	442	0	0	0	445	0	0
Valve Pos. (1/64 in.)	NG	6	NG	NG	92	NG	NG	91	5	91	91	89	NG	-	-
Valve Contact	Closed	Open	Closed	Closed	Closed	Open	Open	Closed	Open	Closed	Closed	-	-	-	-
Alcohol															
Pump Inlet (psi)	NG	NG	1.5	NG	3	1.5	0.3	6.2	7.7	4.7	-7	5.5	3.5	5.3	7.0
Pump (psi)	340	325	337	280	336	363	284	342	344	342	342	340	370	320	292
Before Orifice (psi)	335	320	334	273	330	358	280	337	338	337	337	336	365	318	286
Injection (psi)	49.0	47.0	51.5	12.5	52+	52+	13.0	52+	20.3	52+	52+	56+	56+	53.5	16.4
Δ P-B.O. (Inj. psi)	286.0	273.0	282.5	260.5	278.0-	306.0-	267.0	285.0-	317.7	285.0-	285.0-	280.0	309.0	264.5	269.6
Flow (lb/sec H_2O)	156.8	155.9	155.4	161.9	155.0	159.0	164.2	162.9	104.3	154	-	155.6	161.5	150.8	91.5
Flow (lb/sec Alc.)	134.8	134.0	133.8	139.2	133.3	136.8	141.2	140.1	89.7	132.3	-	133.9	139.0	129.7	78.7
Alc. by-pass Flow (lb/sec)	0	0	0	NG	0	0	70	0	Not meas.	0	-	0	0	0	Not meas.
Valve Pressure (psi)	0	0	0	440	0	0	445	0	447	0	0	0	0	0	510
Valve Pos. (1/64 in.)	88	88	87	12	89	89	NG	87	12	87	87	88	88	89	12

Test No. 6 – Run using 70 percent H_2O_2.

TABLE V

"NORMAL" PORTION OF SPECIAL V-2 PROPULSION UNIT TESTS

Test No.	2	3	4	5	6	Avg
Oxygen						
Pump inlet (psi)	2.5	3	2.5	3.2	3.3	2.9
Pump (psi)	197	198	197	199	202	199
Before orifice (psi)	176	177	177	179	178	177
Injection (psi)	12.5	12.2	11.5	7.1*	13.1	12.3
ΔP-B.O. (Inj.psi)	163	165	165	172*	165	164.7
Flow (lb/sec.H_2O)	141.7	142.8	142.6	141.4	145.1	142.7
Alcohol						
Pump Inlet (psi)	1.5	3	4.7	5.6	5.6	4.1
Pump (psi)	337	340	342	343	340	340
Before Orifice (psi)	334	334	337	339	338	336
Injection (psi)	51.5	52+	52+	56+	56.8	54+
ΔP-B.O.(Inj.psi)	282.5	282-	285-	283-	281.2	282-
Flow (lb sec.H_2O)	155.4	156.1	154	156.4	155.5	155.5

* Values not included in averages.
\+ Gage linkage hit limit.
-O_2 Injection pressure is approximately 6 psi low.

TABLE VI

"SPECIAL" PORTION OF SPECIAL V-2 PROPULSION UNIT TESTS

Test data on runs 2 through 6 corrected to average normal speed of 3840 rpm; control pressure on valves as indicated.

Valve Cont. Pres.	Normal	O_2 On			O_2 & Alc. On		Alc. On	
Test No.	2-6	3	5	Av. 3 & 5	3	4	2	6
Turbine Speed	3840	3988	4022	4005	4120	3960	3930	3712
Oxygen								
Pump inlet (psi)	2.9	4.6	4.5	4.55	4.4	5.3	1.3	2.8
Pump (psi)	199	254	256	255	264	246	202	185
Before orifice (psi)	177	37.5	37.4	37.4	51	30	180	166
Injection (psi)	12.3	2.5	2.1	2.3	2.5	2	11	8.6
ΔP-B.O. (Inj.psi)	164.7	35	35.3	35.2	48.5	28	169	157.4
Flow (H_2O lb per sec)	142.7	75.3	73.3	74.3	79.5	62.5	144.2	138.3
Valve pos. 1/64 (in.)	91	------	------	6*	------	5	------	------
Alcohol								
Pump inlet (psi)	4.1	1.5	3.5	2.5	0.3	7.7	0	7.4
Pump (psi)	340	368	374	371	288	344	280	310
Before orifice (psi)	336	363	369	366	284	338	273	304
Injection (psi)	54+	53	57	55	13.2	20.8	12.5	16.5
ΔP-B.O.(Inj.psi)	282-	310	312	311	270.8	317.2	260.5	287.5
Flow (H_2O lb per sec)	155.5	160	169.6	165	165.3	104.3	161.9	94.3
Valve pos. 1/64 (in.)	88	89	88	88	------	12	12	12

* Taken from test No. 1.
Alc. by pass line open in tests 2 and 3; connected in tests 4 and 6. This accounts for the discrepancy in change of turbine speed and flow with air pressure on the alcohol valve.

(b) Combustion pressure during flight varies directly as the flow; during calibration test, this pressure varies as the square of the flow and is correct at normal operating conditions only. Therefore, changes in combustion pressure due to changes in flow, would not be as great for flight tests as for calibration tests.

Only two of the above discrepancies are of prime importance: (1) reduction of flow in one system does not reduce the combustion pressure in the other and (2) combustion pressure during test varies as the square of the flow instead of directly with the flow as in flight.

The effect of these two discrepancies tend to cancel each other when either the alcohol or oxygen valve is operated separately. This is not the case, however, when both valves are operated simultaneously since only the second condition is (in effect) resulting in a greater change than would be expected under flight conditions. A comparison of test data supports this condition. Using turbine speed as a criterion, the following changes resulted from applying control pressure.

CONTROL PRESSURE APPLIED TO	TURBINE SPEED
Lox main valve	increased 165 rpm
Alcohol main valve	decreased 128 rpm
Lox and alcohol main valves	increased 120 rpm

From these data it can be expected that test results are, in general, representative of flight conditions except when both valves are operated simultaneously. In this case the data should be corrected to a 37-rpm increase in turbine speed. A more detailed analysis of the effects of the discrepancies would be of questionable value since there is only one constant – the power to the turbine and several variables – turbine speed, flow rates, pressures, valve positions, division of horsepower between the two pumps and combustion pressure.

B.6.3 Results

B.6.3.1 General Performance

Propulsion unit operation was very smooth with no pulsations occurring during the application of control pressure on the main valves. It is very likely that the combustion-pressure simulating orifices did not give a true picture in this respect. In the flight it is reasonable to expect that changes in combustion pressure are not in phase with the upstream changes; this may give rise to the severe oscillations the Germans reported.

B.6.3.2 Test Data

All test data are itemized in Table IV. Data during the normal portion of each run, corrected to a 3840-rpm turbine speed, are presented in Table V. Table VI is a compilation of data from the "special" portion of each run. Data in table VI are corrected in proportion to the average normal turbine speed (3840 rpm). All test results are in terms of water flow. Results of test 1 were disregarded since it was obviously in error.

B.6.4 Conclusions

a. Application of control pressure to either the oxygen main valve or the alcohol main valve or both valves will not cut off the propulsion unit through turbine overspeed. Under any of these conditions, the turbine speed will change only about 100 rpm.

b. The thrust under any one of the three test conditions will be approximately one half.

c. Closing the preliminary alcohol valve will result in immediate cutoff by turbine overspeed as soon as the valve actually is closed. It requires approximately seven seconds to bleed the control air from the preliminary alcohol valve.

d. The increased pressures which result from operating either or both valves should not in themselves be sufficient to damage parts or burst lines; however, not included are the effects of pulsations.

APPENDIX C
STEERING SYSTEM COMPONENTS

C.1 GYROS

References: Backfire, Vol. II, p. 136.

During the early part of the V-2 program, the availability of usable control gyros was a serious problem. There were two main types Anschutz and LGW (Fig. 57) available from Germany. However, most of these units were in such poor condition that a general rebuilding was necessary. Both types were used to some extent at WSPG, at times with a pitch gyro of one type and a roll yaw of the other type on the same plate.

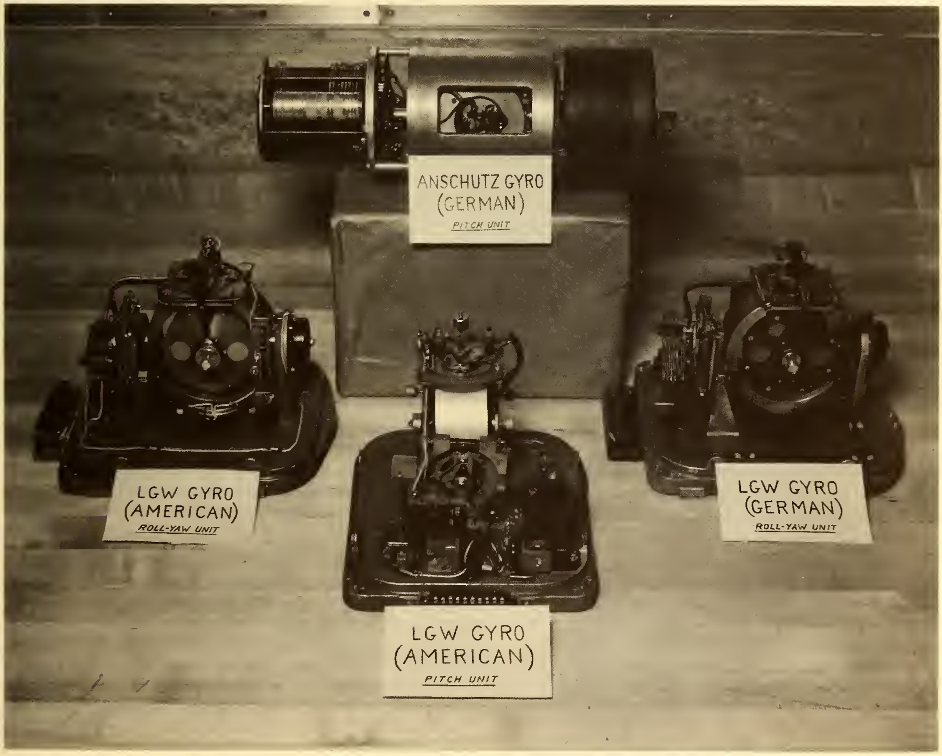


Fig. 57 German and American-made Gyros Used in the V-2 Project at WSPG

C.1.1 Anschutz Type

In general, the construction of the Anschutz gyro was not as neat nor as sturdy as the LGW. The gimbal system consisted of a die-cast gimbal on which was mounted a heavy, two-phase a-c torque motor. The gimbal was pivoted on a cantilever support also of die-cast material. The cantilever support was quite weak considering the weight of the gimbal and motor system. There were a few cases of bending of this cantilever during shipping and handling.

The Anschutz pitch gyro contained an unusual erection device. The gyro axis was erected vertically by two torque motors which were powered through a sensing device such that the torques applied caused the gyro to precess to the vertical. The sensing device consisted of a small dish-shaped, sealed container which was mounted on the bottom of the gyro motor. Within the container was a small amount of conducting fluid and a set of four contacts. These contacts stuck into the container in such a manner that if the unit was not held level, contact was made from one or more of the contacts through the fluid to the dish or common contact, thereby energizing appropriate torque motors.

The program was set in by a d-c timing motor which rotated a porcelain cylinder. The cylinder was coated with a number of silver contact strips on which contact fingers rode,making a circuit through calibrated resistors. This action caused the torque motor to precess the gyro in pitch. Consistent program angles were hard to obtain with this system because the: (1) time duration was affected by variations in d-c supply voltage, (2) torque motor current was directly affected by the a-c inverter voltage and (3) gyro precession rate was affected by the frequency of the a-c inverter.

Some of the most frequent troubles encountered with the Anschutz gyros were as follows:

a. Wiring faults: small size, solid wire was used with insufficient bundling and anchoring.

b. Contacts: the button-type rotatable contacts used for wire lead-ins often opened up either completely or intermittently.

c. Pick-off potentiometers: very inaccessible, making thorough cleaning almost impossible. Contact wipers frequently rode off the pots.

d. Torque motors: two phase a-c type with very small clearance between rotor and stator caused considerable binding if a small amount of dirt entered the air gap.

e. Program timer: silver on porcelain cylinder pitted due to arcing, causing bad contact and occasional snagging of contact fingers.

f. Program resistors did not actually cause much trouble but a large amount of time was consumed in calibration.

C.1.2 LGW Type (German)

The LGW type of gyro was of much sturdier design and allowed easier access to all parts. The gimbal was machined from metal with a much larger cross section than the die cast gimbal of the Anschutz type. Torque motors were much lighter than those of the Anschutz, causing the load per unit cross-sectional area of the gimbal to be much less than the loading in the Anschutz. The gimbal was supported on a cantilever of considerably larger cross-section and with better web reinforcing than Anschutz.

Erection in the vertical axis was accomplished by use of a small pendulum mounted on the gimbal. The pendulum carried a pair of contacts which energized the torque motor to erect the gimbal in a vertical position. Erection of the roll axis on the pitch gyro was effected by a pair of silver contact surfaces recessed into a glass plate. A contact finger riding over the plate energized the torque motor when the gyro axis was not perpendicular to the gimbal axis. A small space between the silver strips represented the perpendicular position. The roll axis of the roll and yaw gyro was erected by using the roll output signal to operate a relay. This relay would energize the torque motor driving the roll signal to zero.

Torque motors on this gyro consisted of a permanent magnet rotor inside two coils, one of which was energized with d-c when a torque was desired. This type of torque motor was limited in the angle over which it would operate but was satisfactory for the LGW (German) gyro; mechanical stops prevented its turning too far.

The programmer on the LGW (German) potentiometer gyro was superior to the Anschutz design in that it turned the gyro potentiometer through the program angle instead of precessing the gyro. It consisted of a program motor driving a cam to which was fastened a metal band. The band passed around a drum on which the pickoff pot was mounted. The total program was adjustable (to some extent) by changing the portion of the cam used and the total turning angle. To reset the device after a test run, the driving arm was disengaged from the program cam thus allowing the cam to snap back to zero position (when the cam snapped back, the metal band occasionally broke). Since the program was originally intended to be approximately 45 degrees on this cam, a lever reduction had to be inserted between the pot drum and the cam for use at WSPG. This was necessary to bring the program angle down to approximately 10 degrees. The program motor was a step type unit which received pulsating d-c from a vibrator in the time switch. Each pulse caused the program motor to take one step. Pulses were at a frequency of 45 per second. Natural frequency of the clapper arrangement was checked on one program motor and found to be approximately 45-47 cps. It is possible that the device was designed this way to make it considerably less sensitive to low battery voltage. At the time this apparent "Tuning" was noticed only one original German assembly was available for test, therefore it was not possible to decide if all units were "tuned" in this manner.

C.1.3 LGW Type (American)

As the supply of both Anschutz and LGW type gyros became depleted it was decided to produce the LGW type in America. Waldorf and Kearns Incorporated were selected to build the domestic units similar to the original German models with a modified program device. The American-made units seemed to be at least as good as the German models in almost every respect. Typical drift rates were of the order of 0.02 degree per minute while the specifications allowed as much as 0.1 degree per minute.

The chief modification between American and German LGW gyros was the program device. The American model used the same program step motor but instead of transmitting motion to the pot with a metal band, the domestic unit utilized a cam following lever. The cam was designed with changing slope to obtain program angles of about 3.7 to 11.0 degrees. An additional modification was made on a few gyros to allow program angles of 72 and 91 degrees for certain missiles. These units used a cam follower with a step-up gear sector and pinion to multiply the rotation obtainable from a cam of reasonable size. The domestic-designed program device was easy to adjust and gave very good repetition of program angles.

The US-program motor would not operate on as low a voltage as the German unit. This may have been due to the fact that the German unit was "tuned," that it had a better iron path or a number of other reasons. When the 72 and 91-degree programmers were made, special attention was given to this operating difficulty. A wider gear was used and the motor was "beefed-up" in general to enable the American model to operate at lower voltage than before but still not as low as the German-made motors.

Alnico magnets used in the American torque motors were stronger than the alloy used in the German models. This made the US-torque motors stronger and able to erect the gyro faster. The plastic forms on which the torque motors were wound did not have as much heat resistance as the German forms. This allowed deforming of the torque motor and binding of the gyro if the torque motor was overheated.

In the German model, the erection contacts that caused the pitch gyro to erect perpendicular to the gimbal (roll axis) consisted of strips of silver recessed in glass. The surface on which the contact-wiper rode was flat. On the American device, the silver was cemented to the glass leaving a depression down to the glass between the silver pieces. The silver was beveled to allow the wiper to ride up the edge easily. This left the edge quite thin and subject to damage by arcing. A filter circuit was installed to reduce the amount of arcing at this point. However, the arcing was still sufficient to cause snagging of the contact wiper where the silver had been roughened. This trouble did not cause very large drift errors in the gyro but was probably one of the most consistent troubles encountered with the American-made gyros.

Originally, the test instructions for the American gyros called for the contact adjustment on the gimbal erection pendulum to be such that the "dead space" (space between erection from CW position compared to erection from CCW position) should be less than 0.1 volt, or approximately 0.04 degrees. Since there was no minimum specified, a few gyros were built with zero dead space. A minimum value of dead space was established to avoid having both torque motors energized simultaneously.

Sparking at the contacts of the pendulum device occasionally caused interference with radio equipment in the missile during ground tests. This was not a critical problem, however, since erection power was cut off at lift.

C.1.4 Test Procedures and Specifications

The following is an outline of the procedures used in tests of LGW (American) gyros:

a. Inspect all solder joints, lead-in contacts, potentiometer windings and wipers.

b. Check continuity and circuit resistances through gyro motor, potentiometers and torque motors.

c. Megger each circuit to ground. Minimum allowable, 10 megohms.

d. Test motor starting and running current, time to full speed and direction of rotation. Starting current should be approximately 2.5 amperes. Running current should be 0.25 to 0.50 amperes. Time to full speed should be less than 2.5 minutes. Motor should turn CCW looking from lead-in end.

e. Test vertical erection (pendulum) from both CW and CCW directions. Dead space should be more than 0.04 and less than 0.06 degrees.

The following tests apply to the roll-yaw gyro only:

f. Set gyro on vibrator-oscillator test table (Fig. 58) with the connector plug toward the west (i.e. gyro axis in a north-south plane when erected). Level the test table and turn on gyro and erection power. When gyro has erected, note the readings on both roll and yaw output signal instruments on gyro test panel (Fig. 58). These zero readings should be less than 0.2 volt (0.08 degrees). Turn off erection voltage for two minutes and read the "wander" for this interval on signal output voltmeters. Yaw "wander" should not exceed 0.2 degree for any two-minute period on three consecutive tests. "Wander" in roll should not exceed 0.4 degree under same conditions.

g. Repeat test f with vibrator and oscillator running during the two-minute intervals. The limits given in f apply.

The following tests apply to the pitch gyro only:

h. Perform both the static and vibrator-oscillator tests of (f) and (g) above, reading the "wander" on the pitch output voltmeter. Wander should not exceed 0.2 degree for any three consecutive tests of two-minute duration.

i. Energize the time switch from the gyro test panel to provide vibrator supply (45 pulses per second) for the gyro program motor. After four seconds the program motor should start operating and run continuously for 48 $\pm$ 1 seconds. The program signal, which is fed to a photoelectric recorder, should increase along the selected angle-time curve until equal to the desired program at 52 seconds (total time). In the case of the seven degree program (the program used most frequently for the V-2 at WSPG), the angle-time curve is essentially a straight line. At the end of the program test, the output voltage to the recorder should stay constant (17.5 volts equals 7 degrees) until the program motor starts to recycle to zero. The final program should be within $\pm$ 0.2 degree of the desired value for three consecutive tests.

j. The coast time for all gyros should be more than 12 and less than 30 minutes.

The following applies to the location of both gyros on the gyro plate:

k. Accurately level the tilt stand (Fig. 59) with the level plate. Install the flight gyro-mounting-plate on the tilt stand, using the machined index fixture to obtain accurate orientation of the plate with respect

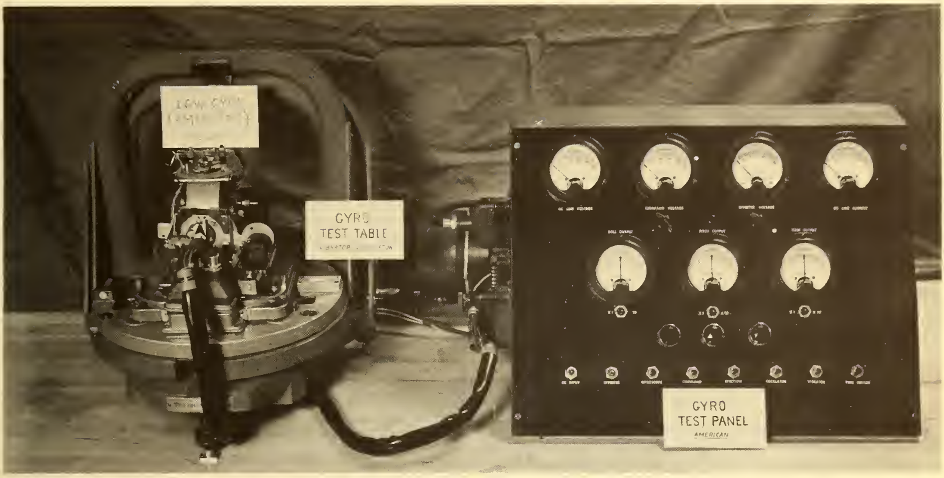


Fig. 58 Gyro-test Table and Panel

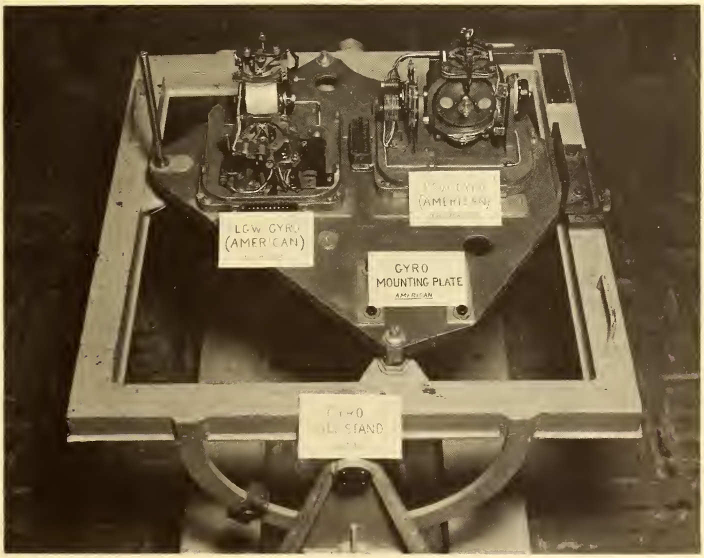


Fig. 59 Gyroscope Tilt Stand

to the stand. Secure the pitch gyro to the plate (the machining of the plate will determine the location of the pitch gyro with sufficient accuracy). Install the roll-yaw gyro with its axis displaced approximately 90 degrees from the pitch gyro. Energize both gyros, including their erection circuits, through the gyro test panel. After both gyros are up to speed and erect, disconnect the erection voltage and turn the tilt stand through the program angle. Note any output signal in either roll or yaw. If either signal is present, adjust the roll-yaw gyro orientation, re-erect the gyro and repeat the tilt test. Continue this test-and-try adjustment until the roll-yaw gyro orientation is such that it produces no signal when the tilt stand is rotated through the entire program angle.

C.1.5 Special Vibration Test

Normally, the gyros were not given a vibration test because it was felt that more trouble would be introduced than would be detected by such tests. However, one US-built gyro was given a rather thorough vibration test.

The gyro was mounted on a standard plate which was attached to the vibration table without shock mounts of any kind. The direction of vibration was approximately 45 degrees with respect to the gyro and gimbal axes.

Preliminary "wander" tests were made to provide a comparative basis for the "wander" rates to be determined after each vibration cycle. The vibration amplitude was changed in steps of 0.01 inch from 0.01 to 0.10 inch. At each step, the frequency was varied from about 10 to 60 cps.

During each test, oscillograms were made of motor current, signal output of the pitch pick-off and vibration table frequency. After each run "wander" rates were checked. The roll rate was measured by an optical system and the pitch rate by the voltage from the pitch potentiometer. The "wander" in a period of five minutes is given below:

TEST	PITCH degrees	ROLL degrees
Before vibration	0.00	-0.11
After 0.01 inch vibration	-0.08	-0.17
After 0.02 inch vibration	0.04	0.11
After 0.03 inch vibration	0.02	-0.06
After 0.04 inch vibration	0.02	-0.11
After 0.05 inch vibration	-0.16	-0.50
After 0.06 inch vibration	-0.12	-0.28
After 0.07 inch vibration	0.02	0.17
After 0.08 inch vibration	0.08	0.06
After 0.09 inch vibration	-0.64	0.06
After 0.10 inch vibration	-0.29	0.23
After return to room temperature	0.64	-3.45

It will be noted that (with one minor exception) the wander rate remained within specification limits (0.5 degrees maximum in five minutes) throughout the tests. After the gyro had cooled down, the static balance along the motor axis shifted enough to create a large drift.

The oscillogram showed that the lead-in leaf contacts opened momentarily at various times in the range of frequencies from 48 to 55 cps. This occurred, in varying degree, at all amplitudes above 0.01 inch.

C.2 MIX COMPUTER (Autopilot servo amplifier)

Reference: Backfire, Vol. II, p. 138.

The name of this device, mix computer, was developed from a translation of the German name, Mischgerät. In this country it would be called an autopilot servo amplifier.

The mix computer as used on this project was a servo amplifier with inputs from the pitch gyro, the roll-yaw gyro, and the jet vanes 2 and 4 synchronizing circuit. There was also a provision for a guide beam (LS) input into the yaw circuit. This input was used with a German radio guidance system to correct the azimuth of the missile during burning. The German guide beam system was never used at WSPG.

From these inputs, the mix computer developed output control current for the four servos attached to jet vanes 1, 2, 3 and 4. It contained the necessary rate networks to make the complete servo system stable.

Both German and American mix computers were utilized at WSPG. The American units were built by the General Electric Company. Electrical circuits were essentially the same in both units; however, the mechanical construction was entirely different.

The German computers were 13 x 9-3/4 x 7 inches over-all, weighed 32 pounds and were constructed with components of a good quality. However, the wire was generally plastic-insulated, solid-copper. This solid wire gave some trouble in test (particularly vibration tests). The wire would break occasionally, probably due to; (1) handling the wire improperly during manufacture, insulation may not have been removed correctly from the wire (and the copper was nicked or weakened) and (2) age (units were old and had been reworked so many times some of the copper wire had been fatigued). It is felt that stranded wire would have been more satisfactory in this application.

From discussions with German personnel and from the appearance of different computers, it was apparent that these units were tested and adjusted by laboratory personnel in Germany. In many units there were wires which had been added to replace wires in the regular cable harness.

For the discussion below, the V-2 rockets launched will be separated into three groups. The chronological listing is included in Table I, page 6.

Group I: In general, missiles 2 through 20 and missiles 25 and 38 (missiles 25 and 38 were chronologically launched during Group III below, but because of the type of mix computers used will be considered part of Group I). Missile 19 had a non-standard V-2 steering system; therefore it is not included.

These missiles all had standard German mix computers with no modifications. Of the 20 missiles in this group, the steering systems of eight failed and gave erratic flights.

The specific components which gave trouble in the German mix computers were wire (as mentioned above), vacuum tubes,dry-disk rectifiers and electrolytic condensers. Vacuum tubes are mentioned here not only because of the number of failures,but also because the supply was short. American-equivalent vacuum tubes were tried in one computer. This computer worked satisfactorily but it was difficult to replace the German tube sockets with American. It never became necessary to make this modification on more than one unit. Dry-disk rectifiers and the electrolytic condensers were replaced with an American equivalent whenever a failure occurred.

Group II: Missiles 21 through 27 (after missile 24, they were not fired in numerical order). Of the eight missiles in this group, the steering system in five failed and gave erratic flights.

During this time one missile was launched by Operation Sandy and is not included here. This missile carried a German mix computer as in Group I but there were modifications to the steering system; the steering system of this missile failed.

Because of the number of steering-system failures, it was decided to mount the German computer in a container designed to keep the unit at atmospheric pressure during flight. This was done to prevent voltage breakdown in the power supply as the altitude of the missile increased. The possibility of voltage breakdown was discussed in General Electric Company - Project Hermes report 45779. In addition, the subject was discussed with German personnel. Their comments were that such a breakdown had been considered in Germany but that it was not believed serious. By enclosing the computer in a pressure tight container, the possibility of voltage breakdown was eliminated; however, the problem of heat dissipation from this container was increased. No method of ventilation (such as circulating air) was used; therefore, high temperature rises were possible.

Group III: Missiles "Special" through 52. Missile 36 had a non-standard V-2 steering system and it is not included.

The mix computers in all missiles of this group were American-made.

When the number of missiles to be launched was increased to 100, it was apparent that there would not be enough German-made mix computers. Therefore, 80 American-made mix computers were built, 60 for the V-2 program and 20 for other programs. These 80 units were to duplicate essentially the German electrical design. To obtain electrical-design data, several German units were disassembled; a new mechanical design was made to utilize standard American components.

The American computers were 13 x 9-5/8 x 7-1/8-inches over-all and weighed 28 lbs. The only difference in the electrical design between the German and American units was in the power supply. The power supply in the German unit was a full-wave, center-tapped transformer type using a vacuum tube rectifier. The power supply in the American version was a voltage-doubler type using a dry-disk rectifier. This power-supply change reduced the secondary voltage of the power transformer one half, which minimized the chance of voltage breakdown.

Six of the American-designed mix computers were built as production samples. Tests performed on these units included: (1) electrical, (2) vibration, (3) cold and (4) hot.

In electrical tests it was found that the gain was low. By adding condensers to tune some of the transformers to 500 cycles the gain was increased to a value equivalent to the German unit. In vibration tests it was found that some components, brackets and shelves were not mounted properly. The components were relocated and the brackets were strengthened. The shelves had additional supports added changing the cantilever type construction to box type. No troubles were encountered in the hot tests.

In general, it was learned that some mechanical changes were necessary to facilitate maintenance. It was also found that the stranded wire being used, although better than solid wire, had poor insulation; this was changed in later units. The exposed shielding on some of the cables gave trouble in the grounding of exposed terminals. This was corrected by adding insulation where necessary.

All missiles (36) in Group III used American-made mix computers. The steering systems of three missiles failed and gave erratic flights. Two of these failures, Bumper No. 7 and 8, were not due to the mix computer.

The first missile of this group "Special" was launched primarily to test operation of new equipment. This rocket was the first in which an American-made mix computer was used. The test was considered satisfactory as a steering system test; however, there were other failures which did not make the flight completely successful.

Starting with the next missile (28) there was some oscillation in vane 2 during test. By replacing the mix computer, this trouble was eliminated. During the launching of missile 25, it was found that there was oscillation of vanes 2 and 4. This oscillation occurred so late in the launching sequence that it was decided to replace the unit with a German computer and proceed with the launching. The steering system performed satisfactorily.

After the launching of missile 25, the cause of the oscillation of vanes 2 and 4 was investigated. It was found that the gain of the vane 2 and 4 synchronizing circuit was sufficient to cause this oscillation. The gain of this circuit was reduced. The vane 2 and 4 synchronizing circuit, of which the mix computer is part, causes the vanes to follow each other. These vanes control pitch only and follow each other to minimize the roll introduced to the missile by the vanes themselves. A switch was added to the Vane 2 and 4 synchronizing circuit to remove the synchronizing signal during final vane balance. This facilitated the vane balance and minimized the effects of a failure in the synchronizing circuit.

During the preflight tests on missile 38 (the next rocket launched after rocket 25) it was found that the 30 mfd rate condensers were breaking down. The condensers are small in size (2 1/4 x 2 1/4 x 2 inches) for their capacity (30 mfd) and voltage rating (100 volts d-c working); they are constructed using a metalized paper process. These condensers had one bad characteristic as far as trouble shooting was concerned; after voltage breakdown caused a portion of the condenser to short out, it would reheal and the condenser would appear perfectly normal. This problem of voltage breakdown with the 30 mfd rate condensers was referred to the manufacturer.

Because of the condenser trouble, missile 38 was launched with a German computer. The steering system of this missile failed.

In view of the trouble with the 30 mfd rate condensers and to give the manufacturer time for tests, it was decided to use the American-made mix computer with German rate condensers. Missiles Bumper 1 through V-2 45, (12 missiles) used this equipment.

Voltage breakdown of the 30 mfd rate condensers was overcome by a heat treating process found to be very effective. Of the 120 condensers subjected to this heat treating process only one could not be used.

At the time Bumper 1 was launched, a considerable amount of electrical pick-up experienced in the mix computer was traced to the guide beam receiver input. This circuit was shorted out to prevent further pick-up troubles; all remaining missiles also had this circuit shorted out.

During the pre-launching tests of Bumper 3, there was a considerable amount of random motion of the command current for vanes 1 and 3. This effect was traced to electrical pick-ups on the leads to the blockhouse. These leads (part of the roll erecting circuit for the roll yaw gyro) were connected directly, to the roll output circuits of this gyro and therefore, were the inputs to the roll circuit of the mix computer. The pick-up gave false signals to the rate network in the mix computer and caused command current fluctuations.

A similar result could also be seen in the pitch and yaw circuits when gusty winds moved the missile. The small motion between the missile structure and gyro pick-offs gave signals to the rate networks and appeared as random variations of command current.

Fluctuations of the roll command current caused by the pick-up were not considered serious. However, since they were undesirable some attempts were made to eliminate them. The two erection leads to the blockhouse were shielded and a condenser was added directly across the leads at the ground stotz plugs (missile drop-away plugs). This method was discontinued because the hazard involved was not considered worth its value.

During later missile firings it was noted that American-made mix computers adjusted in the laboratory would not give the same results when mounted in the missiles. Investigation showed that this trouble was being caused by the output transformers. It was noted that two differences between the German-built and American-built transformers existed: (1) the windings in the German transformers were random-wound while the American were layer wound and (2) the laminations of the American transformers were a better grade of transformer steel than the German.

During investigation of the transformers it was found that if a one microfarad condenser was connected between each side of the computer output to the common lead, the trouble was reduced to a negligible value. Therefore, because of the small number of missiles involved it was decided that the condenser solution was more economical than a transformer re-design. If, however, a large number of these units were to be built for future use, it is recommended that these transformers be redesigned.

The remaining V-2 missiles (48 through. 52) were flown with condensers in the output circuits and with more careful laboratory adjustment.

During the launching of Bumper 6, the servo balancing potentiometers opened circuit and caused incorrect command currents. It was found that in adjusting the potentiometer, the arm was turned past the stop and bent. When it was turned back to the resistance card it would cut the resistance wire. Turning the potentiometer past the stop was a result of improper adjusting of the lock nuts. During this investigation, it was noted that the electrical connection to the ends of the resistance card of the potentiometer were made by a friction fit. For these reasons, a larger potentiometer having better mechanical construction and better electrical connections was used.

C.2.1 Investigation of the American Version of the German Computer

The object of this investigation was to determine the reasons for the variation in operating characteristics between the German and American computers.

It had been found, that a German computer could be tested and adjusted in the laboratory, put in the rocket and pass all pre-firing tests satisfactorily. The American computer would be tested and adjusted to give duplicating laboratory measurements but when placed in the rocket it would not fill the requirements of pre-firing tests.

For the computer investigation, the procedure outlined below was followed. Both a-c and d-c input voltages, variable from zero upward were available. The d-c voltage could be varied from a plus to a negative value and the a-c varied 180 degrees out of phase. Zero-center milliammeters in the center leg of each servo circuit were used to observe the plus or minus d-c current.

When tests for yaw, pitch and roll were made, a signal of ± 6 volts d-c was applied to each input in turn and the output currents recorded. A current of 9 ± 2 ma with an input of 6 volts would have been satisfactory. Equal outputs with both plus and minus inputs were desired. To arrive at equal outputs it was necessary to tune various transformer windings with capacitors and adjust potentiometers in balancing circuits. When satisfactory balance was secured the synchronizing circuit was tested.

During the above tests, the loads were a set of servo-valve coils similar to those used in the missile. It was found that when the American computer was adjusted and balanced for correct operation (9 ± 2 ma with a 6 volt signal) on the laboratory loads, duplicating values of output current could not be secured with missile servo loads. Test results are included in Table VII.

TABLE VII

LABORATORY AND ROCKET TESTS, GERMAN AND AMERICAN COMPUTERS

Roman numerals in heading refer to fins
Arabic numerals in Table are milliamperes

Computer	Sig	Pitch		Yaw		Roll		Sync		Ls		Balance Pot Current				750 Ohms Across Output			
	–	II	IV	I	III	I	III	II	IV	I	III	II	IV	I	III	II	IV	I	III
German 322 in Lab*	0	-1	-1	+1	0	+1	0					-8+6	-9+4	+6-6	+7-5	+6-8	+5-8	+9-10	+10-8
	+6	+8	+8	+10	+10	+10	-8	+6	-10	+13	+13								
	-6	-9	-10	-8	-9	-10	+10	-8	+6	-12	-12								
in Rocket	0	0	0	0	0	0	0					-6+7	-5+6	-10+8	-10+8	-7+7	-8+8	-6+4	+6-5
	+6	+8	+9			+8	-8	+7	-7	+12	+12								
	-6	-8	-8			-9	+9	-7	+8	-13	-13								
American 24																			
in Lab	0	0	0	0	0	0	0					+6-6	+6-6	-4+4	-5+4	+8-8	+8-8	+10-10	+10-10
	+6	+10	+10	+10	+10	+10	-10	+4	-4	+16	+16								
	-6	-10	-10	-10	-10	-10	+10	-4	+4	-18	-18								
in Rocket	0	0	0	0	0	0	0					+4-6	+4-3	-2+3	-3+2	+5-10	+9-6	+7-5	-5-6
	+6	+14	+12	+8	+12	+11	-5			+18	+23								
	-6	-15	-11	-8	-13	-13	+5			-20	-25								

* This computer received no tuning or adjusting for months.

Considered most important were the unbalance and load tests. In the former, the balance pot shown in Fig. 60 was turned to the limits on each side. The current unbalance indicated on the meter should have been 5 ± 2 ma. In the load test, a 750-ohm resistor across one leg of the three control-current leads should have resulted in 9 ± 2 ma. During laboratory tests the computers were tuned to meet these conditions. Results obtained on American computers prepared for firing are included in Table VIII. The differences shown in Table VIII were evident in all American computers tested. Results of the 750 ohm tests were just as variable between the laboratory and rocket installation.

TABLE VIII

LABORATORY AND ROCKET TESTS – AMERICAN-MADE V-2 COMPUTERS

Numerical values in Table are milliamperes

COMPUTER NO.	FIN							
	II		IV		I		III	
17 LAB	+6	-8	+8	-6	-4	+5	+4	-4
ROCKET	+10	-11	+12.5	-11	-7	+7	+5	-12.5
13 LAB	+4	-5	+4	-4	-4	+4	+4	-4
ROCKET	+7.5	-3	+6	-6	-6	+7	+7	-8
26 LAB*	+3	-3	+3	-4	-2	+3	+2	-2
ROCKET	+2	-0.5	+3	-0.5	-6	+3.5	+2	-3.5
24 LAB	+6	-6	+6	-6	-4	+4	+4	-5
ROCKET	+7	-11	+8	-10	-5	+5	+6	-7

* This computer was not worked-over before test. Adjustments were made on gain and balance pots only.

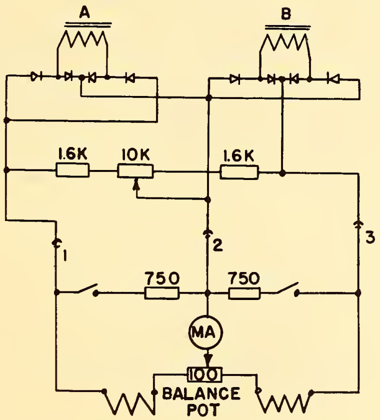


Fig. 60 Computer Output Windings

From the beginning of this investigation it was felt that the main difference was in the output transformer (Fig. 61). Therefore, two German-made and two American-made transformers were tested. Inductance measurements were made of the windings; a General Radio type 650 A inductance bridge was used for measurements at 1000 cycles. The test data are included in Table IX.

It should be noted from Table IX, that winding 1-2 of the American transformer decreased in inductance when other windings were shorted; in the German transformer this winding increased in inductance.

Figure 62 is a log-log plot of the inductance of control winding 1-2 versus the resistance on windings 5 to 7 and 8 to 10. Attention should be directed to the slope of the curves labeled American KV1921 and German, over the operating region. This section is considered the operating range since the load of the servo valve coils fall between these points. The change of inductance in the American transformer is quite large as compared with the German when the loading varies between 220 to 280 ohms.

TABLE IX

TEST RESULTS, GERMAN AND AMERICAN TRANSFORMERS

	GERMAN		AMERICAN	
WINDING	A	B	A	B
1-2	1.07	1.26	8.0	8.2
3-4	2.2	2.25	1.6	1.14
5-7	0.7	0.7	0.55	0.63
8-10	0.58	0.65	0.56	0.67

All windings open except winding being tested.
Numerical values are in henrys.

	OTHER WINDINGS SHORTED				OTHER WINDINGS OPEN			
	AMERICAN		GERMAN		AMERICAN		GERMAN	
WINDING	1000	500	1000	500	1000	500	1000	500
1-2	1.7h	1.25h	3.65h	2.3h	7.8h	6.18h	1.04h	0.73h
3-4	8.5mh		4mh		1.07h	0.65h	1.95h	1.50h
5-7	4.7mh		2.5mh		0.56h	0.47h	0.68h	0.50h
8-10	4.4mh	4.3mh	2.5mh	7.4mh	0.56h	0.45h	0.68h	0.55h

Tests at 1000 and 500 cycles.

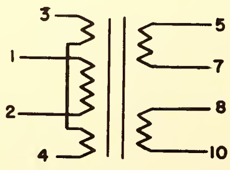


Fig. 61 Schematic Wiring Diagram of Output Transformer

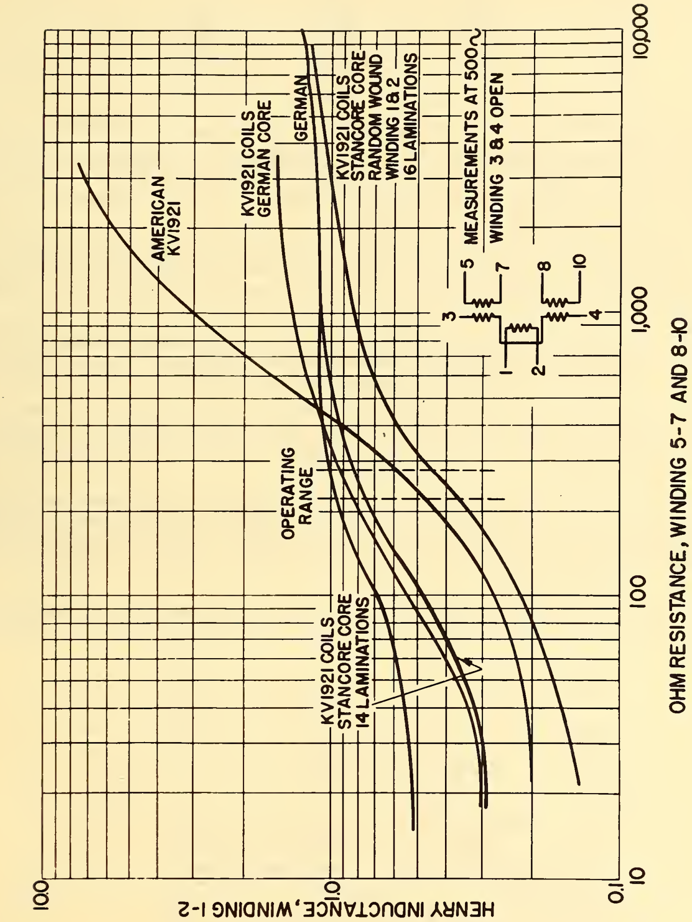


Fig. 62 Inductance in Windings 1 and 2 Versus Resistance in Windings 5-7 and 8-10

To determine the variation in valve coil characteristics a number of servo pumps were measured. The data are indicated below:

INDUCTANCE mh	RESISTANCE ohms	INDUCTANCE mh	RESISTANCE ohms
720	241	575	252
790	242	570	250
625	255	500	252
600	253	505	245
598	245	686	249

The maximum variation was 290 mh (790 to 500 mh) inductance and 14 ohms (255 to 241 ohms) resistance.

From Fig. 60 it can be seen that if an unbalance of 10 ma existed in the circuit due to a control signal applied from the computer through windings A and B, a difference of 14 ohms should not cause a change in the current of more than one-half of one percent. Yet, in the actual operation of a computer, changing the servo had caused a variation in current up to 100 percent.

With the above knowledge, it was felt that the unbalance was due to the reactive effect caused by the variation in inductance of the servo coils. To counter this effect, one-microfarad capacitors were placed across the output leads from the computer. After rebalancing the computer it was found that a change in load caused no appreciable change in current.

To prove that the output transformer in the American computer was the cause of most of the trouble, a set of German transformers was substituted for the KV1921 type. Test results from this modified American computer were comparable to results from the German units.

In an effort to pinpoint the trouble, a KV1921 and a German transformer was disassembled. The German core was inserted in the American windings. Test results are shown in Fig. 62. In addition, laminations from a Stancore Input Transformer, Type A-53-C was found to fit the windings from a KV1921. Test data are included in Fig. 62.

Another set of curves were made on control winding 1 and 2. Initially a volt-ampere test with all other windings open was made (Fig. 63). Then a volt-ampere curve with an excitation voltage of 40 volts, 500 cycles on windings 3 and 4, with the normal load (rectifier and servo pump) on windings 5 to 7 and 8 to 10 was completed (Fig. 64). In operation, the voltage and current in winding 1 to 2 varied between 2 volts at 0.2 ma to 40 volts at 7.6 ma.

In general, it was felt that the type KV1921 transformer was the offending unit and if made to conform more closely with the German output transformer, better operation would result.

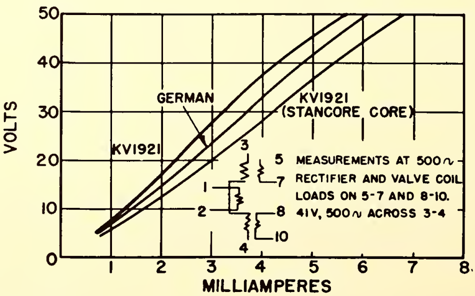


Fig. 64 Volt Ampere Curve With 40 Volts 500 Cycles on Windings 3-4 and Normal Load on Windings 5-7 and 8-10

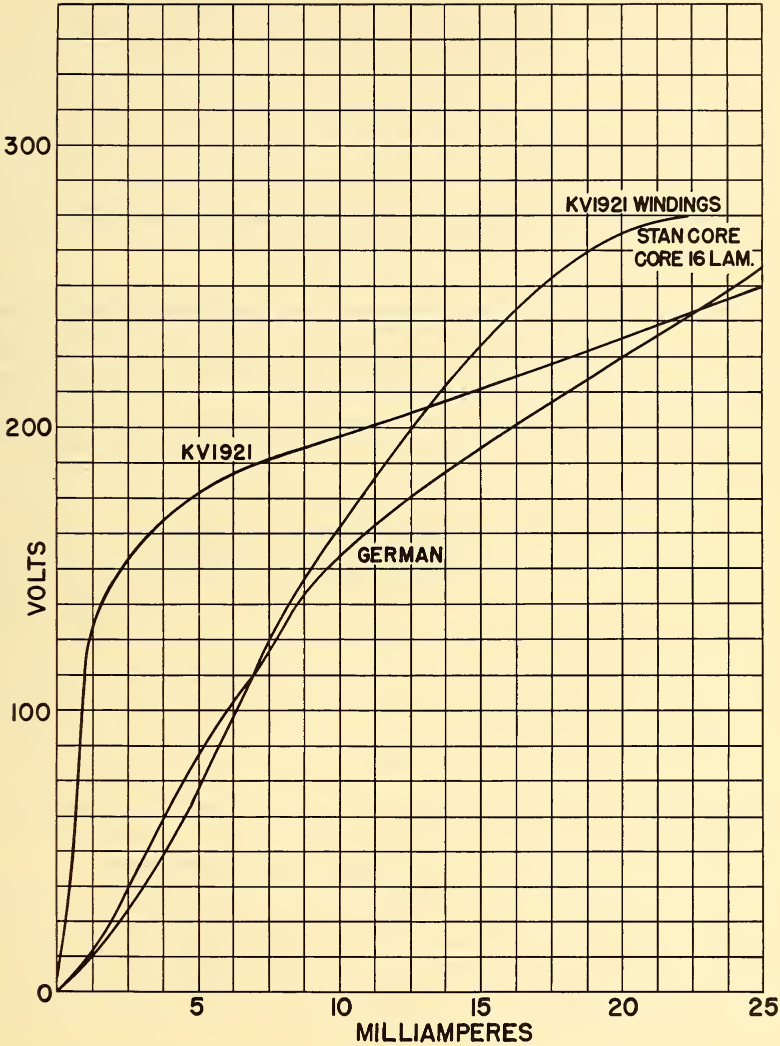


Fig. 63 Volt Ampere Curves for Control Windings 1-2 With Other Windings Open

C.3 SERVO

Each jet vane was driven by a self-contained servo-mechanism[14]. Its basic components were a double-gear pump driven by an electric motor, solenoid-operated control valves, an individual oil reservoir and a hydraulic piston.

An analysis of all in-flight steering troubles indicates that the servo was seldom, if ever, the cause of steering failure. It was, however, one of the weaker components of the V-2 and considerable effort was expended in providing servos which were considered adequate for flight service.

One of the reasons for the marginal character of the servo was the fact that it was not designed for the V-2 but was originally produced for aircraft use. It appears that its power output was somewhat less than would normally be specified for a servo specifically designed for the V-2. Nevertheless, the performance of the servos when new, must have been reasonably acceptable since they were used on some thousands of successful flights in Germany. This assumption is substantiated by the fact that a limited percentage of the servos received at WSPG met the test specifications without difficulty.

Another factor contributing to the servo difficulties at WSPG was wear, particularly in the gear pumps. A number of different types of gears were found in the pumps. Some were hardened while others were of relatively soft steel. Some had a smooth finish while others showed tool marks very clearly. As might be expected under such conditions, some showed the effects of wear in a short time while others were much less susceptible. With a fairly extensive amount of testing at WSPG, added to an unknown amount of running in Germany, many of the servos fell below the specified performance.

Some servos would pass test specifications with cold oil but fail when the lubricant reached a higher temperature. The following tables show the failure point for 132 servos received in one shipment.

TEMPERATURE ^{o}C	NUMBER OF SERVOS EXCEEDING SIX-SECOND LIMIT	NUMBER OF SERVOS STALLING
35	13	9
40	33	9
45	18	6
50	26	2
55	9	2
60	3	0
65	1	0
70	1	0
	104	28

The following table shows the average time required to produce a rise of $5^{o}C$ with the servo running at no load.

TEMPERATURE ^{o}C	AVERAGE TIME REQUIRED Minutes	NUMBER OF SERVOS IN AVERAGE
35-40	4.2	108
40-45	4.3	66
45-50	4.4	45
50-55	3.7	14
55-60	6.0	5

From the above data it was evident that it would be necessary to improve the performance of the weaker servos if trouble was to be avoided in the latter stages of the program. It was hoped that sufficient improvement could be realized through the use of some hydraulic oil having a smaller change of viscosity with temperature. An investigation showed that the Germal oil was approximately equal, in this respect, to the hydraulic oils available in this country. This meant that any appreciable improvement in viscosity index would have to be obtained through the use of a silicone oil. Tests demonstrated(15) that silicone oil could not be used in the servo gear pump without modification because of the high probability of seizure. Modification of the pumps did not appear justified because the improvement in performance was not great and was partly neutralized by poor circulation of the fluid in the servo case.

The German pump motor was known to have exceptionally poor speed regulation. Application of full load would reduce the motor speed to approximately 50 percent of its no-load value. It was evident that great improvement could be expected by substituting a motor which would hold a reasonably constant speed over the normal load range.

No standard motor was found which would satisfy the requirements of this application without modification. Eventually it was necessary to rewind a motor originally designed for aircraft service. The performance of the motor was very satisfactory, holding speed within about three percent from no load to full load.

However, the improved motor performance was obtained at the cost of weight and power requirements. The individual German servo weighed 17 pounds. The servo with the new motor weighed 25 pounds. No-load current was doubled, increasing from an average of four amperes for the German motor to an average of eight amperes for the new motor. To meet the added current requirements, a third main-power battery was added to the two normally carried.

At the same time that the motor was replaced, each servo was thoroughly reconditioned. Pump gears and pistons were replaced and cylinders were re-lined if required. After this overhaul each servo was given a complete set of tests at the factory. This was followed by similar tests at WSPG prior to installation in the missile. Sample test sheets are shown in Fig. 65 and 66.

The result of the motor change and the overhaul was an outstanding increase in performance. Average time required to complete the full travel was reduced to about 2.3 seconds. Previously, the time varied from 6+ seconds to a complete stall.

Neither the motor substitution nor the overhaul introduced serious troubles. There were three minor difficulties, all concerned with oil leakage. Initially a lead gasket was used at the adapter plate between the new motor and the servo case; considerable leakage resulted. A fiber gasket was tried but no appreciable improvement was obtained; a neoprene gasket proved satisfactory. There was also some leakage past the oil seal on the shaft of the motor. The problem was to obtain an oil-tight seal without placing unnecessary load on the motor or causing heating of the shaft at 4000 rpm. A change in the type of seal produced acceptable results. The third trouble was the "wicking" of oil from the servo case by the control wiring. A number of interim remedies were tried with some improvement. None were entirely successful. Selection of wire with suitable insulation avoided this trouble.

Low power output, as previously discussed, was the defect responsible for the majority of rejected servos at WSPG. Two other defects, drift and low sensitivity, accounted for most of the remaining rejections.

Excessive drift was the result of improper adjustment of the zero position of the two control valves. Test specifications required that with no mechanical load and with zero signal current, the time of movement from one extreme to the other must be greater than 30 seconds. The servo design included adequate provisions for adjusting the position of the valves, but the actual process was rather difficult. This was due (in part) to the fact that a change in adjustment to improve drift was very likely to upset the adjustment with respect to sensitivity. The valves were delicate and were sensitive to very small changes in adjustment. Special test facilities would be required to do the job properly. The rejections for excessive drift were not considered large enough to justify the construction of such facilities at WSPG. Consequently, adjustments for drift normally were not made at WSPG.

Test specifications for sensitivity stated that the servo must move a load of one meter-milogram very slowly with a differential control current of $\pm$ 4 ma. The foregoing comments regarding valve adjustments apply to sensitivity as well as drift; such adjustments seldom were made at WSPG.

V-2 TEST

SERVO TEST REPORT

Type Motor __________ S.N. __________

Type Test __________ Date __________

TESTED BY __________

TIME	OIL TEMP °C	NO LOAD CURRENT amps R	L	FULL LOAD CURRENT amps R	L	NO LOAD TIME seconds R	L	FULL LOAD TIME seconds R	L	LIFT pounds R	L	AMBIENT TEMP °C oil	air

Remarks:

Sensitivity R L OK NG

Zero Posit. R L OK NG

Oil Level

Insulation Resistance

Location

WALDORF INSTRUMENT CORPORATION

103 Lafayette St., New York, N.Y.

TEST RECORD – SERVO (V-2, A-4) SERIAL # 111

							Noted Temp.
Prelim. - Angle	L	38.5	R	40			
Pump No.		208					
Idle Press	L	80	R	80			33
Relief Press	L	730	R	730			
No Load Current		7.5 Amps.					33
1. - Creep .... (30°)	L	O.K.	R	O.K.			33
2. - No Load Time .... (30°) Max. 1.5 sec. Diff. .1 sec.	L	1.19 Sec.	R	1.20 Sec.			34
3. - Sensitivity............ (30°)	L	O.K.	R	O.K.			35
4. - 66# Load Test .... (35°)		Amps.		Sec.	P.S.I.		
Max. 4.0 sec.	L	13.5		1.84	570		42
Diff. .5 sec.	R	13.0		1.86	570		
5. - Scale Test............ (40°)		Amps		Scale #	P.S.I.		
Min. 80#	L	18		86	730		43
Diff. 10#	R	17		86	730		
6. - 66# Load Test .... (50°)		Amps.		Sec.	P.S.I.		
Max. 6.0 sec.	L						
Diff. 1.0 sec.	R						
7. - Scale Test .... (50°)		Amps.		Scale #	P.S.I.		
Max. #	L						
Diff. 15#	R						

Tested: __________ Approved: __________

Fig. 65 and 66 Sample V-2 Servo Test Sheets

The German test specification called for the servo (with 28 volts applied and a control current of 30 ma) to move from one extreme to the other, without load, in less than 1.6 seconds. With a 30 meter-kilogram load, the maximum time should be less than six seconds. A special test panel and load fixture[16] (Fig. 67) provided facilities for accurately measuring the travel time. This type of test was used exclusively during the earlier part of the program. In 1947 facilities were arranged for measuring the stall-torque for both CW and CCW motion.

Fig. 67 V-2 Servo Being Tested With Load Test Panel

C.4 TIME SWITCH

Reference: Backfire, Vol. II, p. 132.

The German time switch was satisfactory and was used with only a few modifications at WSPG. These modifications usually consisted of slight wiring changes and some changes in time of operation of certain cams. The switch consisted of a regulated-speed d-c motor which, through a gear train, turned a cam shaft mounting 14 cams. These cams actuated switches at various times depending on the calibration of the cams.

The vibrator that furnished power for the gyro program motor was also mounted in the time switch cam. This vibrator consisted of a vibrating metal reed tuned to vibrate at 45 cps. It was mounted between two contacts such that when it hit one contact it gave a pulse of current to the program motor in the gyro and when it hit the other contact it energized an electromagnet which kept the reed vibrating. Dirty contacts and misalignment of the reed constituted most of the troubles encountered with the time switch. The test panel and time switch are shown in Fig. 68.

The following is an outline of the test procedure followed in preparing the time switches for missile use.

a. Megger each circuit to ground. Should be more than 10 megohms.

b. After making necessary cam adjustments and associated wiring changes, check timing of all cams to be used in proposed missile flight. All should be within $\pm$ 0.1 second of desired time for any three consecutive tests.

c. Check time for a complete cycle of the time switch. Should be 90 $\pm$ 2 seconds over a 25 to 30 volt range.

d. Be sure the vibrator will start repeatedly and will continue to run with the time switch mis-oriented from its prescribed missile position up to $\pm$ 30 degrees.

e. Check time switch in conjunction with the pitch gyro proposed for use and the spare. The gyro program motor must operate reliably over a range of 26 to 30 volts, when supplied by the vibrator of the time switch tested.

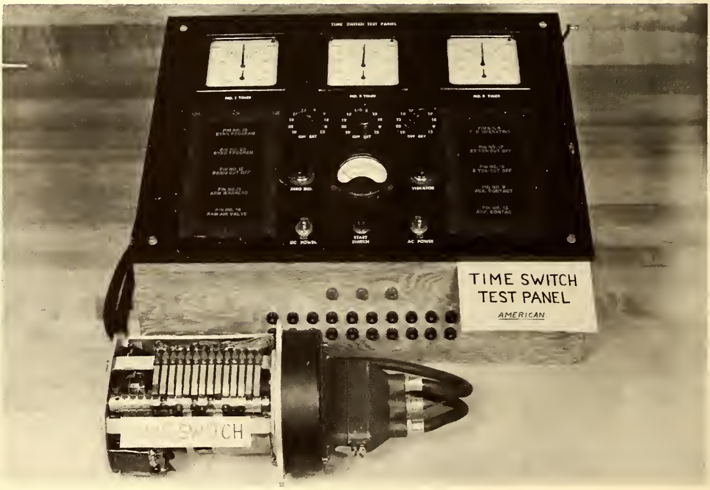


Fig. 68 V-2 Time Switch and Test Panel

C.5 INVERTERS AND REGULATORS

Reference: Backfire, Vol. II, p. 129

The inverter and regulator set proved to be a very dependable unit. It supplied 500 cycle a-c power for operation of the gyro motors and the missile servo amplifier. The inverter unit consisted of a d-c adjustable-speed motor driving an alternator with a six-pole permanent-magnet rotor and a wound stator. The regulator was a rather unique unit with no moving parts. The frequency sensitive portion of the circuit consisted of two inductance-capacitance tuned circuits, one tuned slightly above 500 cps and the other tuned slightly below 500 cps. In series with each of these tuned circuits was a bridge rectifier circuit. Direct-current from these rectifiers flowed through two saturable reactors which controlled flow of a-c current into another rectifier, the output of which operated the control field of the d-c motor driving the inverter. Each tuned circuit tended to make the inverter operate at its frequency. This system held the frequency to about one-tenth of one percent with as much as 10 percent change in line voltage. Adjustment was obtained by changing one of the adjustable inductors. Difficulties with the inverters and regulators consisted mostly of sparking at the brushes of the inverter and poor soldering or broken connections in the regulator. Radio interference was encountered a few times but seemed limited to individual cases where brush sparking was a little worse than usual. Since there was a large supply of these inverters, no attempt was made to repair an occasional troublesome unit. The original German wiring system used a List 14 pole plug. Because the supply of the matching plug was limited, the plugs were removed and an American terminal board substituted. The inverter, regulator and test panel are shown in Fig. 69.

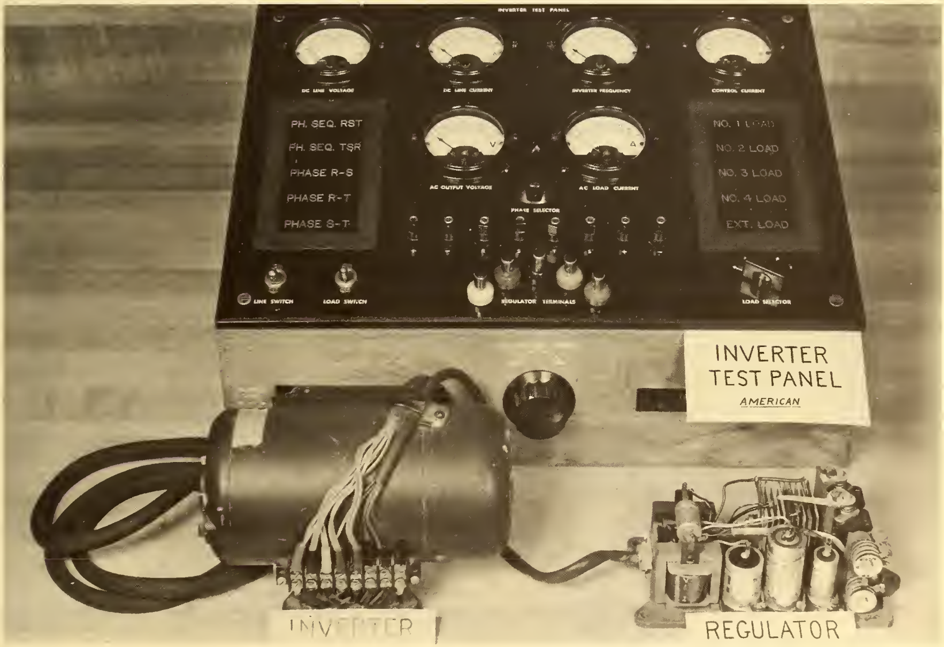


Fig. 69 Inverter Regulator and Test Panel

The following is an outline of the test procedure used for the inverter and regulator.

a. Remove German List 14 pole plug and replace with a Jones-type strip. Connect regulator to inverter terminals and anchor new connector cable to inverter case.

b. Remove regulator case; visually inspect all solder joints and connections. Check for capacitor grounds to base.

c. Apply d-c line voltage (with load switch off) and observe test panel instruments for any abnormalities. Check regulator adjustment to be sure it will cover the desired range (500 cycles).

d. With supply voltage set at 29.5 volts, turn load switch on; after inverter has taken up the load, adjust the regulator for 500 cycles (the load is a bank of two gyro motors in parallel).

e. Turn voltage down to 27.5 volts, frequency should remain at 500 $\pm$ 1 cps.

f. Turn voltage down to the point at which the regulator can no longer control the frequency. This voltage must be less than 25 volts.

g. Megger each point on terminal strip to ground. Must be more than 10 megohms.

APPENDIX D
MISSILE FAILURES

D.1 SUMMARY

MISSILE NO.	PROBABLE CAUSE OF FAILURE	TIME OF FAILURE (seconds after start of lift)
2	Broken jet vane	at lift
8	Pump bearing seized	28.2
10	Open circuit in wiring to servo	13.9
11	Pickup in guide-beam circuit	at lift
14	Failure in computer or roll-yaw gyro	2.0
16	Open circuit in pickoff potentiometer of pitch gyro	at lift
18	Failure of power supply in computer	38.0
20	Failure of tube in computer	24.3
24	Failure in computer	57.5
26	Failure in yaw gyro	at lift
27	Failure of tube in computer	48.4
29	Pickup in guide-beam circuit	at lift
30	Open circuit in wiring to servo	27.0
32	Break in alcohol piping	10.7
37	Open in control circuit to alcohol preliminary valve	56.4
38	Open in computer or roll-yaw gyro circuit plus open in synchronizing pot	13.0
39	Hydrogen peroxide tank not fully loaded	at lift
40	Open in control circuit of alcohol main valve	45.2
42	Computer failure or open circuit in control wiring	22.0
45	Poor regulator operation plus high winds	at lift
46	Cutoff relay operated through undetermined failure in control system	25.7
50	Intermittent contact in control circuits for both main propellant valves	43.4
52	Leak in alcohol piping	8.0
54	Break in lox tank pressurizing system	at lift
55	Separation explosives detonated	at lift
57	Leak in alcohol piping	15.5
Bumper 2	Failure in control circuit of alcohol preliminary valve	33.0
Bumper 4	Break in alcohol piping	28.5
Bumper 6	Cutoff relay operated by undetermined failure in control system	47.5
Bumper 7	Sneak circuit in erection system of pitch gyro	lift
Bumper 8	Sneak circuit in erection system of pitch gyro	lift
Special	Failure in control system for alcohol preliminary valve	36.6

D.2 INDIVIDUAL REPORTS ON FAILURES

The following pages contain detailed description of each failure with comments concerning the probable cause.

MISSILE 2

Performance

The motion of the missile was erratic from lift; thrust was terminated by radio at 19 seconds.

Data

No telemetry equipment was carried on this missile. The only sources of information on missile behavior were photographs and visual observations.

Remarks

The type of gyrations executed by the missile could have been caused by breakage of one of the carbon jet vanes. There are a number of possible causes of this breakage such as inclusions, voids or other defects within the vane itself. There is also the possibility that the vane was struck by one of the ignitors as it was blown from the motor. On later missiles an elaborate series of tests and precautions were taken to prevent vane breakage. The vanes were X-rayed and given a mechanical load test. The mounting threads (tapped in the carbon) were given a torque test. Protection against damage by the ignitors was provided by thick cardboard covers for the vanes. These measures apparently were effective since no other missile acted in a way as to suggest vane breakage.

Probable Cause

A broken jet vane.

MISSILE 8

Performance

Missile operation appeared entirely normal up to 28.25 seconds. The velocity was about five percent above the general average and the steering was good. At 22 seconds (time of the last good trajectory data) the pitch program was developing normally and the east-west deviation was only 40 feet. At 28.25 seconds there was an explosion which broke up the missile.

Data

Optical instruments provided the following information:

a. Missile velocity was about five percent above the general average

b. Pitch program was developing normally

c. East-west deviation at 22 seconds was 40 feet.

Telemetry data was somewhat questionable due to the loss of certain calibration equipment[17]. The time of the explosion was recorded as 28.25 seconds.

Recovery after impact was particularly valuable. The bearing of the oxygen pump showed clearly that it had overheated and seized.

Remarks

Seizure of the oxygen pump bearing could be expected to wreck the oxygen pump, the alcohol pump, and the steam turbine. An explosion in the tail would certainly be expected to follow.

Probable Cause

Rust on the oxygen pump shaft, resulting in failure of the oxygen pump bearing.

MISSILE 10

Performance

The flight appeared normal up to 13.9 seconds. Steering and propulsion were both good. At 13.9 seconds the missile went into a spiral motion. The motor was cut off by radio at 20 seconds.

Data

Optical instruments provided the following information:

a. Missile velocity was about 10 percent above the general average.

b. At 13.9 seconds the deviation from the north-south line was about 40 feet west.

c. There was some north movement, indicating that the program was starting.

Telemetry results were good and showed that:

d. Vane 3 moved rapidly to its extreme position at 13.9 seconds.

e. Shortly after 13.9 seconds, vane 1 moved in a direction to counter the roll-producing action of vane 3 as described in d.

Remarks

Missile movements were those that would be expected if vane 3 moved to an extreme position. The action of vane 3 can best be explained by an open circuit in the control wiring to that servo. Output of the computer is fed to the servo over a three-wire circuit. The middle wire is connected to the common point of two control solenoids. The outer wires connect the opposite ends of the solenoids to the computer. The solenoids are arranged to oppose each other. Under balanced conditions the solenoids receive equal amounts of current, but no movement takes place because of their opposing action. If one of the outer wires is opened, one solenoid is de-energized and the other causes the jet vane to move to an extreme position. The action of the vane strongly suggests that such an open circuit occurred. Since the steering was good for over 13 seconds, it seems probable that the open circuit was caused by vibration.

Probable Cause

An open circuit in one of the control wires connecting the computer to the servo.

MISSILE 11

Performance

Immediately after lift the missile turned to the east. After about four seconds it had reached an angle of approximately 70 degrees from the vertical. At about this time the missile rolled so that fin 1 was up. The rocket continued in fairly level flight about 300 feet above the ground with slight turning toward the north. Radio cutoff was given at about 6.5 seconds.

Data

Telemetry records were good. Starting from the instant of lift, vanes 1 and 3 moved rapidly to a deflection of about seven degrees in such a direction as to turn the missile east.

Remarks

Calculations indicate that a seven-degree deflection of the vanes would produce movement in reasonable agreement with that observed. It therefore became a question of what caused the vanes to act improperly.

Prior to launching it had been necessary to adjust the vane-balance potentiometers twice to stop vane drift. At the time, this was attributed to temperature changes. Experience in Germany had shown that this might be expected if the missile stood for over one hour after oxygen loading (stand time in this case had been 100 minutes). However, the subsequent action of the missile could not be explained by temperature change alone. Calculations indicated that the observed vane action could be expected if the original cause of unbalance, which had made readjustment necessary, were removed at lift. One such possibility would be the opening (due to vibration) of a circuit within the computer. It is not reasonable to believe that the open occurred beyond the computer, because both vanes started to move in the same sense at the same instant and their last common junction is within the computer.

Later experience indicated another possibility. The original computer was designed to accept guide-beam command in yaw. This was a relatively high-gain circuit and it was necessary to short the input terminals of the computer when guide-beam command was not used. There is no certain knowledge that these terminals were shorted on this particular computer. If the short was not present, it is possible that the yaw channel was being influenced by pickup from the ground control cables. This could explain the need for readjustment of the vane balance. It would also explain the disappearance of the spurious signal when the ground-control cables were dropped and the missile lifted.

Probable Cause

A spurious yaw signal resulting from induced potential in the guide-beam circuit of the computer.

MISSILE 14

Performance

Takeoff appeared normal and the missile flew normally for about two seconds. At this time it appeared to go into a combined roll and yaw. After a few gyrations it headed south, flying approximately level and having a periodic oscillation from south to west. Cutoff was given by radio at about 31 seconds.

Data

Telemetry records were satisfactory. From these records, it was found that during the first two seconds of flight the rocket corrected two minor deviations and held on course in a normal manner. After two seconds, a combined roll and yaw movement of the vanes took place, but no vane moved to zero or to an extreme position. Vanes 2 and 4 remained synchronized.

Remarks

The fact that the missile corrected successfully for early deviations indicates that all polarities were correct and that the gyros, the computer and the servos were all functioning normally at the start. Since the telemetry record shows that the servos continued to operate, it appears reasonably certain that the servos were receiving spurious signals in both roll and yaw. An attempt was made to find some circuit in the computer that would duplicate the observed effects, however, this attempt was unsuccessful. It is reasonably certain that the trouble originated in either the gyro or the computer, but there is no evidence to suggest which was at fault.

Probable Cause

A failure in either the roll-yaw gyro or in the computer.

MISSILE 16

Performance

The missile tipped north rapidly during the first three seconds after lift. At the end of three seconds the angle with the vertical was in the order of 15 degrees. This angle increased gradually to approximately 21 degrees at the end of powered flight. Azimuth angle, from the north-south line, varied in an erratic manner but was less than two degrees at the end of burning. During the earlier part of the powered flight the velocity ran a few percent below the general average, but the maximum velocity was much higher than normal due to an unusually long burning time.

Data

The following data were obtained from the tracking instruments:

a. According to Doppler data the missile velocity was as follows:

TIME (seconds after lift)	VELOCITY feet per second	PERCENT OF AVERAGES
10	325	-7.1
20	772	-3.5
30	1303	-3.6
40	1914	-2.2
50	2755	-1.6
60	3971	-0.7
69	5204 (max)	*

* Only two missiles launched during this program exceeded 5204 fps.

b. East-west movement was erratic during the powered flight:

East-west movement

Built up gradually from	3 fps at 3 seconds
to westward movement of	44 fps at 20 seconds
Dropped abruptly to	10 fps at 21 seconds
Continued gradual decrease to	1 fps at 31 seconds
Reversed direction at	31 seconds
Slight eastward movement to	38 seconds
Gradually increased (west) to	46 fps at 54 seconds
Averaged	41 fps to 62 seconds
Reversed direction abruptly	at 63 seconds

Deviation from north-south line was 1058 feet west at end of burning.

c. Photographs of the launching show that the missile began to tip north within one second after lift. Within two seconds, the angle with the vertical was approximately 10 degrees. Thereafter, the apparent pitch angle (calculated from increments of range and altitude) ran as follows:

PERIOD	AVERAGE PITCH ANGLE degrees
4 to 8 seconds	19.2
8 to 12 seconds	19.0
12 to 16 seconds	19.8
16 to 20 seconds	19.3
20 to 24 seconds	17.2
24 to 28 seconds	17.8
28 to 32 seconds	17.2
32 to 36 seconds	18.5
36 to 40 seconds	19.0
40 to 44 seconds	18.9
44 to 48 seconds	18.8
48 to 52 seconds	18.5
52 to 56 seconds	19.2
56 to 60 seconds	19.8
60 to 64 seconds	20.4
64 to 68 seconds	21.2

Except for the first three seconds after lift, the telemetry records were good. The action of the jet vanes during the first three seconds would have been of much interest, but the record was completely lost during that period. Beyond three seconds, the data showed the following:

d. The turbine speed action appeared normal throughout the powered flight, with a steady-state value of approximately 3800 rpm. From about 80 to 100 seconds, the turbine was turning slowly (about 100 rpm).

e. The combustion chamber pressure remained essentially constant at about 190 psi during the powered flight. After burn-out the readings failed to drop in the proper manner. At 71.5 seconds there was an abrupt drop to approximately 80 psi. Starting at 75.5 seconds the pressure reading showed a gradual rise to about 125 psi. This value continued to at least 110 seconds.

f. All four vane positions were recorded and showed unusually large deflections. Vanes 2 and 4 showed excellent synchronization throughout the record. Starting with a pitch-north deflection of five degrees at five seconds, they moved steadily to a pitch-south deflection of nine degrees at 22 seconds. Subsequent action was recorded as follows:

Fairly steady decline to 3.0 degrees pitch south at 26.5 seconds
Fairly steady rise to 8.0 degrees pitch south at 31.0 seconds
Fairly steady decline to 3.0 degrees pitch south at 34.5 seconds
Fairly steady rise to 7.0 degrees pitch south at 39.0 seconds
Fairly steady decline to 5.0 degrees pitch north at 53.0 seconds

There was no additional change of any appreciable magnitude to the end of burning.

The function of vanes 1 and 3 was the control of both roll and yaw. The recorded positions of these vanes have been resolved into equivalent roll and yaw position as follows:

Yaw approximately constant at about 4 degrees (yaw east) to 15 seconds. A gradual movement to about 7.6 degrees (east) at 26 seconds. A return movement to about 3.0 degrees (east) at 42 seconds. A gradual increase to 5.6 degrees (east) at 47 seconds. From this time to the end of the record, the vane angle varied from 3.1 to 3.9 degrees (east).

Roll showed minor fluctuations around the zero position up to 8 seconds. From 8 to 15 seconds the angular deflection of the vanes was approximately 1.5 degrees in such a direction as to produce clockwise roll. Starting at 15 seconds there was a gradual and fairly constant movement which continued to a deflection of 14 degrees in such a direction as to produce CCW roll. From 28 to 44 seconds this deflection averaged about 11 degrees. Starting at 44 seconds, the angle gradually decreased until the roll correction reached approximately zero at about 62 seconds. Thereafter, there was no appreciable change in the position of the vanes.

All vanes showed one peculiar change. Normally, the trace of vane position is not completely smooth but shows ripples, or minor fluctuations. This was true of all four vanes up to 50.5 seconds. At that time, the trace of all vanes suddenly became exceptionally smooth. After that time, additional vane movements occurred but the trace remained unusually clean.

Remarks

Evidence indicates that the missile held a pitch angle of 19 ± 2 degrees. The pitch-angle plot leaves some question as to whether the normal pitch program of 5 degrees was superimposed on a fixed angle of approximately 15 degrees. There is a suggestion that it did, but the data are not conclusive.

Much of the evidence points to the pitch gyro as the origin of the abnormal pitch angle. In general, the failure of any steering component, other than the gyro, would result in a continuing turn or in a purely random motion. In this case the missile appears to have been steered along a more-or-less fixed angle. In addition, vanes 2 and 4 were exceptionally well synchronized. This establishes, beyond reasonable doubt, that: (1) all power sources, (2) a part of the computer and (3) all steering components beyond the computer, were operative. If the preceding items are eliminated, only the gyro, the command battery and the input circuits of the computer remain.

The pitch gyro in this missile was of the Anschutz type. The pickoff potentiometer consisted of two segments, each wound in an arc of approximately 175 degrees. However, the full arc was not used. Each potentiometer was tapped at points 20 degrees (plus and minus) from its center position; the command potential was brought in at these taps. The most probable location for an open circuit in one of these potentiometers would be near one of the taps.

If one of the pickoff potentiometers should open at any given angular location, the steering system would be satisfied only when the missile had assumed a corresponding angle. For example, assume that one potentiometer opened at a point 10 degrees from its center. If the pickoff wipers were on center, one half the full command potential would appear as a gyro output signal. The polarity of the signal would be such as to drive the missile, and the wiper, in the direction of the open. The signal would not become zero until the open was reached. If the wiper was driven across this open, a strong signal of reverse polarity would appear; this would operate to drive the missile and wiper back toward the open. Thus, the steering system would try to hold the missile at an angle corresponding to the angle of the open.

Assuming an open circuit in the pickoff potentiometer near the 20-degree tap, the above sequence would appear to offer a reasonable explanation of the observed trajectory. Unfortunately, the telemetry record of vane positions offers nothing to confirm this theory and (in some respects) suggests the presence of some other type of fault. The discrepancies are most pronounced in the position of the pitch vanes. According to the data, the pitch vanes were in a pitch-south position from about 13 to 48 seconds, while the missile was certainly pitched north. If this actually was the case, then these vanes were opposing some other force. This point should not be given too much weight, however, because there is the possibility that the records are in error as to polarity.

Another suggestion of an extraneous force is the fact that the pitch vanes began to move toward their zero position at about the same time that "Q" (1/2 PV^2) started to decrease. It should also be noted that the pitch vanes had an average displacement of approximately five degrees from 17 to 43 seconds. During this 26-second period, the apparent missile pitch angle showed remarkably little change; starting at about 19 degrees, dipping to about 17 degrees and returning to about 19 degrees. During the same period the roll component of vanes 1 and 3 was unusually large, averaging about 10 degrees.

The action of the vanes suggests the possibility of unusual aerodynamic forces. It seems possible that some structural distortion may have been produced by the rapid turn at the start of the flight.

Probable Cause

An open circuit, near the 20-degree tap, in the pickoff potentiometer of the pitch gyro.

MISSILE 18

Performance

Missile performance was satisfactory for about 38 seconds. Velocity was approximately 15 perceht above the general average and steering was adequate. At 38 seconds the deviation from the target line was about 200 feet west. The pitch program angle was 4.85 degrees compared to a desired value of 4.95 degrees. At about 40 seconds the missile started to roll. Since there was no danger of the missile leaving the range, radio cutoff was not required. Burn-out occurred at about 60 seconds.

Data

Optics and doppler provided the following information:

a. Missile velocity was approximately 15 percent above the general average

b. Deviation from the target line was about 200 feet at 38 seconds

c. The pitch program was developing properly (4.85 degrees compared to 4.95 degrees desired at 38 seconds).

d. At about 40 seconds there was a pronounced change in the deviation rate and in the program angle.

e. Doppler data indicated that a roll started at about 40 seconds.

Telemetry records were adequate but their usefulness was impaired because of a lack of voltage calibrations. It was necessary to fly a transmitter without calibrations due to technical difficulties with the telemetry. Some useful information (noted below) was obtained on the basis of relative values.

f. Vanes 1 and 3 showed oscillation, with a period of approximately 0.6 second, from lift.

g. The movements of vanes 1 and 3 indicated correction for a combination of both roll and yaw.

h. At about 38 seconds, all four jet vanes moved toward their center positions. Vane 4 steadied almost exactly at center while the others appeared to settle a few degrees off center. No appreciable movement of vanes 1 and 3 took place until burning ended. Vanes 2 and 4 remained steady to about 50 seconds. From this time to the end of burning the vanes showed some activity.

i. Starting at 40 seconds, noise appeared periodically on the telemetry record.

Remarks

There is no suggestion of a malfunction in the propulsion system other than the fact that the thrust was somewhat higher than normal. This was probably the result of poor performance of the air-pressure regulator. The reduced burning time is in reasonable agreement with the observed increase in thrust.

It appears that the steering system was working steadily from lift to maintain roll-yaw control. All evidence indicates that as long as the steering system was operative, adequate control was maintained. In fact, pitch control appears to have been exceptionally good.

All four vanes started toward center at the same time indicating the failure of some component common to all vanes. Among such common components are: (1) inverter supplying the computer, (2) power supply within the computer, (3) command battery and (4) power leads to the servos.

If any of the above are lost, the vanes are driven toward center by the jet.

As well as can be determined from the telemetry record, the change in conditions appears to have taken place abruptly, possibly within 0.1 second. This tends to eliminate the command battery since a decline in battery voltage would be expected to be more gradual. A complete loss of command voltage, by open circuit, would be possible, but this seems unlikely since vanes 2 and 4 show appreciable motion between 50 seconds and burn-out. The same objection applies to the loss of a common power lead to the servos and to the complete loss of the inverter; it is difficult to conceive of a partial loss of an inverter.

Available information suggests an abrupt drop in all servo signals to a value which would allow the jet to drive the vanes back to approximate center, but not a complete loss of signal. Under this assumption, a very strong signal from the pitch gyro might produce the observed motions of vanes 2 and 4 after 50 seconds (section h of Data above). Vanes 1 and 3 would not be equally susceptible to gyro signals because they were mechanically coupled to their respective air vanes and would therefore offer greater resistance to movement away from center.

It is suggested that some fault within the computer, perhaps the partial loss of effectiveness of the power tube, caused the internal power supply of the computer to drop to a critical value.

Probable Cause

Partial failure of the internal power supply of the computer.

MISSILE 20

Performance

For about 27 seconds missile performance was excellent. Velocity was approximately 15 percent above the general average. Steering was good, with a deviation from the north-south line of only 133 feet at 27 seconds. The pitch program was developing normally. At about 27 seconds the east-west motion reversed direction and the pitch motion showed a disturbance. At 37.3 seconds the missile began to roll. At the end of burning the roll rate had reached one rps. Combustion chamber pressure began to drop at 55.5 seconds and burning ended at about 58 seconds.

Data

Telemetry records were satisfactory and showed the following:

a. Aside from a momentary disturbance at lift, the jet vanes showed very little activity up to 20 seconds.

b. At 20 seconds vane 3 began to show an oscillation of increasing amplitude.

c. At 24.3 seconds vane 3 moved rapidly to its center position and remained there to the end of the record.

d. From 20 to 24.3 seconds vane 1 acted as if it were working to correct a combination of roll and yaw. When vane 3 ceased to function, vane 1 immediately went into an oscillating motion similar to that previously seen on vane 3.

e. Vane 1 became relatively inactive from 30 to 33 seconds. At 33 seconds it started a slow movement toward an end position. At 36.5 seconds the end position was reached and at 37.3 seconds a continuous roll started.

Remarks

It is clear that the final cause of trouble was the loss of jet vane 3. The subsequent action of the other vane, and of the missile itself, were those that would be expected under the circumstances.

There are many different faults which would cause a vane to go to its zero position, but a few of these can be eliminated. First, the roll-yaw gyro did not appear to be at fault because vane 1 reacted in a proper manner when vane 3 was lost. Second, the command battery and the computer inverter were not suspected since the other vanes continued to function normally. For the same reason, the power supply within the computer was not suspected.

The following possibilities remained:

a. An open wire in the vane 3 circuits of the computer

b. Loss of the vane 3 electronic tube in the computer

c. An open circuit in the middle leg of the command circuit to the servo

d. Loss of drive power to the servo pump

e. Some type of mechanical failure within the servo

Of the above, the loss of the electronic tube seems most probable. Old German tubes were used; these had shown a fairly high failure rate when subjected to tests on a vibration table. All telemetry records indicate considerable vibration near the speed of sound. This failure occurred within two seconds of the time at which the missile reached that speed.

Probable Cause

Failure of an electronic tube in the computer.

MISSILE 24

Performance

Missile performance was normal up to 57.5 seconds. Velocity was within five percent of the general average and the steering appeared to be normal. Deviation from the north-south line was less than 100 feet at 40 seconds and there was no significant change of angle prior to 57 seconds. The pitch program was fair. Starting at 57.5 seconds, the missile began to roll.

Data

The experimental equipment aboard this missile required a maximum number of telemetry channels leaving only two channels for monitoring missile performance. These two channels were assigned to turbine speed and combustion chamber pressure. There was no telemetry data on the steering system.

Remarks

In the absence of any information on the steering system, there is no way to eliminate any of the possible sources of roll. Among the many possible sources were the following:

a. Fault in roll-yaw gyro

b. Fault in computer

c. Fault in servo

d. Failure of command battery

e. Failure of inverter supplying the computer

f. Fault in wiring anywhere in steering system

In general, the computers showed less reliability than the other devices listed above. For that reason only it is considered the most probable source of the trouble.

Probable Cause

Computer failure.

MISSILE 26

Performance

Starting at lift, or very close, the missile flew a remarkably straight course approximately 40 degrees east of north. The pitch program was near normal and the velocity was very close to the general average.

Data

The telemetry channels assigned to missile performance did not produce data due to some failure within the telemetry transmitter. The only information available for analysis of the steering trouble consisted of trajectory data obtained by optical and doppler means. The trajectory data appeared to establish the following:

a. Missile velocity was normal

b. Pitch movement was near normal

c. The missile did not roll prior to burn-out

d. East movement was not proportional to the missile velocity

e. In general, the east movement held a fixed relation to the north movement.

Remarks

Since the pitch movement was approximately normal, it can be assumed that servos 2 and 4 were operative. Since no roll occurred, it can be assumed that servos 1 and 3 were operative. The same evidence would indicate that the command battery and the computer power supply were not at fault. The fact that the yaw angle appeared to increase gradually from zero to about six degrees, over a period of 60 seconds, does not suggest the breaking of a wire. It is difficult to conceive of a fault in the computer which would produce such a gradual increase in yaw angle. By elimination, the yaw portion of the roll-yaw gyro is suggested as the most probable source of the faulty steering.

Probable Cause

A fault in the yaw portion of the roll-yaw gyro.

MISSILE 27

Performance

Throughout the powered flight, the missile velocity was approximately 11 percent above the general average. Up to 48.4 seconds the azimuth steering was exceptionally good, the total deviation at that time being only 90 feet (west). At 48.4 seconds there was an abrupt increase in the west movement; shortly thereafter the missile began to roll. Since the roll prevented any further increase in the azimuth angle, the missile was not cut off.

Data

Trajectory data, from optics and doppler, indicated the following:

a. The missile velocity was approximately 11 percent above average.

b. At 50 seconds the pitch angle of the trajectory was 5.2 degrees.

c. At 48.4 seconds there was an abrupt increase in west movement. For the preceding 10 seconds, the average west velocity was less than 2 fps. In one second this value increased to 17 fps. In 10 seconds the west velocity had increased to 257 fps.

d. The start of roll is not precisely indicated. It appears to have been after 52 seconds but before 57.4 seconds.

Telemetry data indicated the following:

e. The turbine started to slow down at about 62 seconds.

f. Jet vane channels showed no motion throughout the flight. This undoubtedly was the fault of the telemetry system since the vanes must have been operating.

Remarks

In the absence of information regarding jet vane actions, any analysis must be based on trajectory information. If the west movement had developed at 30 or 40 seconds, it might have been possible to determine whether the movement was due to roll or yaw. Since the movement started within about three seconds of the end of the program, a selection between roll and yaw is not clear. Since the west movement may have been caused by a slow-starting roll, all elements of the steering system were subject to suspicion. The only remaining basis for the choice of a particular element is the general reliability of the various elements. On this basis it seems most likely that the fault originated in the mix-computer.

Probable Cause

Failure of tube in mix-computer.

MISSILE 29

Performance

Within the first two seconds after lift the missile showed movement to the east. During the first 13 seconds very little, if any, north movement was apparent. This resulted in a large azimuth angle east of north. At about 13 seconds north movement started. This movement increased fairly rapidly; the azimuth angle began to decrease. At about 31.5 seconds the missile reached the safety limit and was cut off by radio.

Data

Trajectory data, obtained by optical means, indicated the following:

a. East motion occurred within the first two seconds.

b. The average eastward velocity was a fixed percentage of the missile's total velocity. The apparent yaw angle was about 2.5 degrees.

c. There was no north movement during the first 13 seconds of flight. After 13 seconds the north movement was fairly close to that of a seven-degree program.

Telemetry data were available for turbine speed, jet vane position (four vanes) and missile position with respect to its roll, yaw and pitch axes. These data indicated the following:

d. The missile did not roll during powered flight.

e. Immediately after lift, a yaw angle appeared and remained relatively constant to 17 seconds. From 17 seconds to the end of the powered flight a larger yaw angle is indicated.

f. The pitch angle showed no significant change during powered flight.

g. In general, the vane movements were of small magnitude. Maximum departure from zero position (for any vane) was about three degrees.

h. All vanes showed enough activity to indicate that they were operative.

i. There were definite indications that vanes 2 and 4 were synchronized.

j. All vanes showed increased activity near the speed of sound.

Remarks

Since there is evidence (section d. above) that the missile did not roll, from (b) above the missile apparently maintained a reasonably constant yaw angle from lift (section b. above). This suggests that a fixed bias appeared in the yaw steering system at lift. If such bias had been present prior to lift, it would have been seen in the steering command to servos 1 and 3.

The fact that north movement did not develop as early as expected does not appear to have any connection with the yaw trouble. The lack of early north movement might be attributed to: (1) a slight delay in the start of the program, (2) a program of less than the expected seven-degree maximum or (3) temporary cancellation of the north movement by the wind. The trajectory data was not smooth enough to allow a definite selection among these alternatives. It appears, however, that the velocity and direction of the wind could explain fully the temporary delay in north movement.

While there was no apparent connection between the delay in north movement and the yaw failure, it should be noted that this delay did exaggerate the azimuth angle produced by a relatively small yaw angle. In this respect it was a contributing factor in making cutoff necessary.

Since the missile appeared to be under control, although flying a fixed yaw angle, there is little cause to suspect the command battery or the servos. The gyro or the computer might be suspected, but the fact that there was no evidence of roll tends to weaken this suspicion. The computer, in particular, seems unlikely since the same tubes are used for both roll and yaw control.

There is another possibility which appears to fit all the known conditions. The guide-beam part of the yaw circuit was not being used. If there was pickup on this input, it could have been balanced out by the vane balance potentiometers (an angle of 2.5 degrees was within the range of these pots). If the pickup originated in the ground controls, it would disappear at lift, leaving a fixed bias in yaw. To satisfy this bias, it would be necessary for the missile to fly a corresponding yaw angle.

Probable Cause

Pickup in the guide-beam input to the yaw control.

MISSILE 30

Performance

Steering in azimuth was satisfactory, with a deviation of 400 feet (west) at burn-out (62.5 seconds). Range at burn-out was 3970 feet, which was about one half that expected. Propulsion was above normal, with missile velocity about 18 percent above the general average. After burn-out the missile moved south at a low rate and west at a somewhat higher rate. Impact was approximately 3.25 miles west and 1.0 miles south of the launcher.

Data

Optics, doppler and telemetry all gave very useful information. Trajectory data, from optics and doppler, indicated the following:

a. Missile velocity was about 18 percent above the general average.

b. The missile pitched about 16 degrees to the north immediately after lift, followed by a pitch south of about 10 degrees.

c. After a few oscillations (resulting from the initial disturbance) the missile began to move north at a rate corresponding to a normal seven-degree pitch program. This continued up to about 27 seconds.

d. At approximately 27 seconds the apparent pitch program began to decrease slowly (from about three degrees at 27 seconds to about 2.2 degrees at 54 seconds.

e. At about 54 seconds the apparent pitch program began to decrease rapidly, reaching zero degrees at about burn-out.

f. The north position of the missile remained approximately constant from burn-out to about 120 seconds. After that time the missile had a slow south movement to impact.

g. At burn-out the missile had moved 422 feet west at an average rate of about seven feet per second. After burn-out the west velocity increased to approximately 60 fps at 120 seconds. From this time the west velocity remained essentially constant to impact.

Telemetry data indicated the following:

h. There is some evidence that the "desensitizer" functioned during the first three seconds of flight and that it was at least partially removed at approximately three seconds.

i. All four jet vanes were operating normally up to 27 seconds.

j. The pitch vanes were very closely synchronized up to 27 seconds.

k. The roll-yaw vanes began typical oscillations as the speed of sound was approached.

l. Jet vane 4 ceased to function at approximately 27 seconds. It moved to its zero position in about 0.3 second and remained there to the end of burning.

m. Jet vane 2 began a mild oscillation at 30 seconds. This disappeared at about 46 seconds. It is clearly shown that the roll-yaw vanes were responding to movement of vane 2 during this period.

n. When burning ended, vanes 1, 3 and 4 moved to a position other than zero.

General information is as follows:

o. This missile was launched with a tilt of 1.5 degrees to the north.

p. A "desensitizer" was used to reduce the servo response to gyro signals during the first three seconds of flight, after which it was supposed to be removed automatically from the circuit.

q. The center of gravity (missile not fueled) was 226 inches. This was several inches below that normally desired. The normal lox load was reduced by 1000 pounds to increase the initial loaded center of gravity.

Remarks

In view of the impact location, it would be reasonable to suspect that the program did not start or did not function properly. Trajectory data, however, clearly establishes that the program was developing normally up to 27 seconds.

There was also the possibility that the "desensitizer" was not removed from the circuit as planned. Telemetary data gave a fairly strong indication that it was at least partially removed. The subsequent action of the vane tends to confirm this. This is particularly evident for the roll-yaw vanes (they were able to prevent roll after vane 4 ceased to operate).

It is quite clear from the telemetry data that vane 4 ceased to operate at or near 27 seconds. Since the performance had been normal up to that time, it is reasonable to assume that this failure was the origin of the unusual trajectory.

The fact that a single pitch vane was unable to maintain a normal pitch program does not seem unreasonable. The pitch thrust for a given gyro signal would be reduced and the synchronizing circuit would attempt to hold the active vane in the same position (center) as the inactive vane. Under these conditions any sort of stability in pitch could be considered remarkable. It is also suprising that the steering system was able to counteract the roll-producing effects of the single pitch vane.

It seems clear that the roll-yaw system continued to operate in a very effective manner and that the unusual trajectory can be explained by the loss of vane 4. If this is true, all common components of the steering system are above suspicion. The servo, wiring and one small part of the computer remained as questionable.

There is very little basis for a choice among these alternatives. Perhaps the least likely is the servo. A mechanical fault in the servo would probably show up as a gradual decline in its activity. No such decline was noted. If the motor should stall due to mechanical binding, the load on the power battery would be so great that there would be little probability that the steering system could remain effective for 35 seconds longer.

Ordinarily a computer fault would be selected in preference to a wiring fault on the basis of general reliability. In this particular case the situation is modified by the fact that additional equipment (the "desensitizer") was connected in the servo circuit. Although this device was tested thoroughly, its reliability in flight had not been established in the same degree as the normal V-2 components. In any event, its presence introduced additional connections which increased the possibility of open circuits in the command line to the servo.

Probable Cause

An open circuit in the command line to the servo.

MISSILE 32

Performance

Missile velocity was approximately 15 percent below the general average. The steering appeared to be satisfactory, although, normally, little can be determined about the steering during the first ten seconds of flight. At 10.7 seconds there was a fairly violent explosion in the tail. After the explosion, the missile began to roll and to veer to the west. Thrust continued to about 24.7 seconds when a second explosion took place.

Data

Optical records indicated the following:

a. Missile velocity was approximately 15 percent below the general average.

b. There was very little north-south or east-west movement prior to the first explosion.

c. Photos show clearly a fairly violent explosion in the tail at 10.7 seconds.

d. The jet continued strong after the explosion.

e. There was no photographic evidence of any abnormal condition prior to the explosion.

f. A second explosion occurred at about 24.7 seconds at which time the jet stopped abruptly.

Telemetry offered no useful information because of a fault within the telemetry system which produced excessive jitter.

Recovery provided the following information:

g. Various tail hatch covers were torn off leaving many of the holding screws still in place.

h. The burner was recovered in one piece although one side was mashed flat. The burner was cut open for inspection but no evidence of trouble was found either inside or outside. The nuts which secured the alcohol and oxygen pipes to the burner were all still securely in place.

i. There was no evidence of appreciable burning within the tail. Many pieces of tail skin were recovered but they did not show signs of burning. Many tail cables remained clean.

Remarks

In the absence of useful telemetry data, there is very little that can be learned concerning the cause of the explosion. Good telemetry data would have indicated whether there was any connection between the low thrust and the explosion.

Certainly, there is the possibility that the cause of low thrust was also the cause of the explosion. One objection to this theory is the time element. An alcohol leak of sufficient volume to produce the observed reduction in thrust would be expected to produce an explosive concentration in the tail in less than 10 seconds (trajectory data indicated that the thrust was low from lift or shortly thereafter).

One possible explanation for a delayed explosion could be the absence of a source of ignition during the first few seconds. On all missiles elaborate precautions were taken to eliminate all potential sources of ignition. Assuming that there was no source within the tail, ignition might have resulted later if there was a flow of alcohol from the tail to the jet.

It is highly probable that the explosion resulted from alcohol vapor. The only other source of such a violent explosion would be hydrogen peroxide. In this particular case it seems unlikely that there was any appreciable break in the peroxide system since the turbine continued to run for approximately 14 seconds after the first explosion.

Probable Cause

A break of appreciable size in the alcohol system.

MISSILE 37

Performance

The missile velocity was about 18 percent below the general average. Steering was good with the program very close to the intended value and a deviation of about 250 feet west at burn-out. Burn-out occurred prematurely at 57.5 seconds.

Data

Trajectory data, obtained from optics and doppler, showed the following:

a. Missile velocity was about 18 percent below the general average.

b. The pitch program was slightly above the intended seven degrees at 52 seconds.

c. West velocity averaged about four fps with a total deviation at burn-out of 250 feet.

Telemetry data showed the following:

d. Low-air pressure was 395 psi (about 17 percent low).

e. Combustion chamber pressure was 175 psi (about 17 percent low).

f. Turbine speed was 3550 rpm (about nine percent low). The turbine started to overspeed at 56.4 seconds and reached its peak of 5370 rpm at 57.3 seconds. There is telemetry evidence that the missile was cut off at about this time. This was to be expected since the overspeed trip was tested for 5150 rpm.

Remarks

The low air pressure, low turbine speed, low combustion pressure and low missile velocity were probably the result of a poor pressure regulator. This regulator (in general) proved to be inconsistent and unreliable in its operation.

The turbine overspeed, resulting in missile cutoff, was almost certainly caused by unloading of one or both of the pumps. Tests have proved that the main oxygen and alcohol valves cannot be closed fully against pump pressure and that such partial closure will not result in any appreciable increase in turbine speed. This leaves three major possibilities for unloading the pump or pumps: a large rupture in either the alcohol or oxygen system, the exhausting of alcohol or oxygen or the closing of the alcohol preliminary valve.

A rupture in the propellant piping system cannot be dismissed as highly improbable. The piping system was subjected to severe vibration and to extreme temperature changes. It would be expected, however, that such a rupture would be followed immediately by a fire or an explosion. Since two telescopes tracked the missile for 170 seconds and reported no such occurrence, the probability of piping trouble was diminished.

There is little probability that the alcohol supply was exhausted. The quantity loaded was checked by two independent means; a meter on the alcohol pump and float switches in the alcohol tank. In addition, the color of the explosion at impact suggested the presence of considerable alcohol; also there were strong alcohol fumes at the crater the following day.

The exhaustion of oxygen might be suspected because the missile remained at the launching site for three hours and ten minutes after oxygen was topped. Simple calculations show this to be highly improbable. From a number of topping operations, oxygen boil-off rates have been established to an accuracy of about 95 percent. The established rate is 6.5 pounds-per-minute for the first hour and 5.7 pounds per minute thereafter. Initial oxygen loading was completed at 9:35 PM and topping at 12:15 AM. Therefore, the boil-off after topping should be based on a rate of 5.7 pounds per minute; the loss for 190 minutes should be about 1080 pounds. For a typical launching the loss would be about 560 pounds and the burning time would be 65 seconds or more. The loss for this missile exceeded the typical figure by 520 pounds, which would equal 3.4 seconds of burning time at the normal rate. Thus under normal conditions, less than half of the lost burning time is explained. In this particular case the propellant consumption rate was at least 10 percent below normal. This increases the expected burning time to at least 71 seconds and thereby widens the discrepancy.

There is the possibility that one propellant was exhausted prematurely because of some error in the selection of the orifice which controlled the mixing ratio. This is highly improbable. To account for the lost burning time in this way would require a very large error in mixing ratio. The alcohol orifice was 125 mm diameter and the oxygen orifice 92 mm. Calculations show that (for this particular missile) the mixing ratio would be changed only 1.6 percent if the two orifices were reversed. This would not be true for all missiles. For some missiles, a reversal of this kind could result in a change of perhaps 15 percent in mixing ratio. But in this particular case the characteristics of the propulsion system were such that a large change in orifice dimensions would have little effect on the mixing ratio.

The most probable cause of the turbine overspeed is premature closure of the alcohol preliminary valve. This valve is doubly susceptible to accidental closure because the loss of either air pressure or electrical power will cause it to close. The circuit to hold this valve open includes one relay contact, one connector and a number of wiring junctions plus one auxiliary control valve. The opening, or failure, might be anywhere within this system. There is no data to aid in locating the source more closely.

Probable Cause

An open in the wiring of the control circuit for the alcohol preliminary valve.

MISSILE 38

Performance

Between 13 and 29 seconds the missile was observed to roll 40 to 50 degrees counterclockwise and back to normal four times. At approximately 29 seconds a continuous roll in a clockwise direction started. At the moment the continuous roll started, the pitch program was about 10.5 degrees (three times normal). After roll started, the missile settled on a course about 20 degrees west of north. Missile velocity was close to the general average. At about 57 seconds the missile was cut off by radio.

Data

Telescopic data indicated the following:

a. At about 13 seconds the missile rolled about 40 degrees CCW and then rolled back to its normal position. Similar rolls started at about 16.5, 20.5 and 24.0 seconds. The magnitude of the roll appeared to increase slightly with each cycle. After the return from the last cycle, the missile held its normal position for about one second and then started a continuous CW roll. The first full roll was completed in about eight seconds.

Trajectory data, from optics and doppler, indicated the following:

b. Missile velocity was close to the general average.

c. The pitch program showed a steady increase at about three times the normal rate. At 28 seconds the pitch angle was approximately 10.5 degrees.

d. From 18 to 28 seconds the west velocity was nearly constant at about 30 feet per second. Total deviation at 28 seconds was about 475 feet (west). At about 29.5 seconds the west velocity started to increase rapidly.

Telemetry data indicated the following:

e. Vanes 1 and 3 showed no movement from their center position.

f. Vanes 2 and 4 showed a most unexpected action. For approximately five seconds they showed no movement from their center position. From five to 12 seconds there were possible minor excursions from center. From 12 to 27 seconds, the pitch vanes showed a rather consistent cycle of about five seconds duration. During one half of this cycle, vane 4 remained near center while vane 2 moved about five degrees in such a direction as to produce CW roll. During the other half-cycle vane 2 remained near center while vane 4 moved about five degrees in a direction to produce CCW roll. The complete cycle had a remarkably consistent period of about four seconds. In general, a given vane moved from center in one direction only. The only appreciable exception occurred a fraction of a second before continuous roll started. At that time, vane 4 showed about three degrees of movement to the opposite side of center. There were brief instances when both vanes appeared to be synchronized in pitch-producing movements. It should be noted that the vane-position channels were commutated and information on vane position was available for only one third of each second.

g. The missile carried a roll-measuring gyro which was telemetered. The total deflection of the recording pen was 3/8 inch for 360 degrees of roll. Consequently the accuracy of roll readings was limited. Within this limitation, the telemetry record confirms the telescopic data on roll as given in a. above. There is a suggestion on the telemetry record that one or two smaller rolls occurred prior to the first observed by the telescopes, but this is subject to question.

Remarks

The telemetry showed a constant reading of approximately 2.5 volts for vane 1 and vane 3 for the duration of the record. It is hard to conceive of a fault in the telemetry which would produce this type of record. It is equally difficult to believe that both position potentiometers became disengaged simultaneously after lift. It is therefore accepted that neither vane 1 nor vane 3 moved.

Two independent means have established that the missile rolled CCW and returned to its normal position at least four times. Without roll control, the missile would be expected to develop a continuous roll in one direction because of imperfect positioning of the fins. But to return to normal position, after having rolled away, requires jet vane action. Since vanes 1 and 3 were inactive, the roll force in at least one direction must have come from vanes 2 and 4.

If vanes 2 and 4 produce roll, one servo must be much faster than the other or the synchronizing circuit must be abnormal in some respect. Servo trouble is almost out of reason in this particular case. Test records on the two servos show that their speed was reasonably close. Of more importance, the roll period was entirely too long to be explained by differences in servo speed. Further, the telemetry record of vane movements does not support this possibility.

The symmetry of the vane movements, as shown by the telemetry, strongly suggests that the synchronizing circuit was operative, although the manner of operation was abnormal. Also, there were brief periods when the vanes appeared to be synchronized in a normal manner. This directed suspicion to the synchronizing potentiometers which were attached to the vanes.

An open circuit near the center of one potentiometer would explain many of the recorded actions. This, together with the previous assumption of vanes 1 and 3 being inactive, would appear to satisfy all the available data.

To explain the apparent fact that each vane usually moved on only one side of center, it is necessary to locate the open a few degrees to one side of center of the potentiometer. The maximum movement of the vanes suggests that this be in the order of five degrees from center.

It seems probable that the open occurred shortly after lift. Otherwise, the strong synchronizing commands should have been noted in test and on the steering desk. Since the record shows that the vanes remained at center for approximately five seconds, it is suggested that the open occurred at the time the program started.

The following explanation of the missile's action is offered: When the synchronizing potentiometer (sync pot) opened, it appeared to the sync circuit that the particular vanes had moved to an extreme position; it is assumed that the pot on vane 4 opened. The sync circuit started to move vane 4 away from center toward the open. At the same time, the sync circuit started to move vane 2 away from center in the opposite sense. During this time the pitch program was applying a signal to the vanes. The pitch program added to the movement of vane 4 while it opposed that of vane 2. This tended to drive vane 4 faster than vane 2. Thus, vane 2 remained near center while vane 4 moved in a direction to produce CCW roll. This movement continued until vane 4 reached the open and thus removed the sync signal.

If the pitch pickoff were satisfied with the missile angle, all servo signals would disappear and the jet would drive the vanes back toward center. When the sync pot wiper again made contact with the pot, the above cycle would start again. This cycle would repeat until further pitch-north signal was received.

When further pitch-north signal was received, the sync pot wiper would be driven across the open in the pot and make contact to reverse the sync signal. This would cause reverse motion of both vanes but by then the program and sync signals were opposed for vane 4 but added for vane 2. Thus, vane 2 would move faster than 4 producing CW roll.

It should be noted that when the missile roll (CCW) reached approximately 30 degrees, the roll gimbal of the pitch gyro came up against a stop which caused the pitch gyro to precess in a direction to increase the pitch-north signal. This in turn increased the vane action to produce CW roll and return the missile to its normal roll position. The excessive pitch program can be explained also in this manner.

When the CW roll had pulled the gyro gimbal away from the stop, the precession ceased and the CW force decreased. Apparently there was a type of balance between the normal pitch action and the inherent roll tendency of the missile. This seemed to operate to bring the CW force to zero or the missile stability caused the vanes and the missile to reach their center positions at about the same time. Thus, conditions were set up for the start of a new cycle.

The question remains as to why the missile finally took off on a continuous CW roll. This could have been caused by some disturbance in pitch (perhaps a wind gust) which gave a strong pitch-north signal just before the missile started a new CCW roll. It should be noted that the final roll started in the speed-of-sound zone where disturbances are to be expected.

The cause of the inactivity of vanes 1 and 3 remains in question. In view of the activity of vanes 2 and 4, it seems certain that no common component of the steering system was at fault. It seems equally improbable that the fault was in the two servos or their individual components, since this would imply simultaneous and like failures in the time between final test and lift. This points to the probability of a fault in equipment or wiring which was common to the roll-and-yaw system only. These would include the roll-yaw gyro, a limited number of components of the mix-computer and the associated wiring. The computer seems improbable since it has no tube common to both servos and very few parts of any sort that are common to servos 1 and 3 only. Normally, the gyro would be among the last devices to suspect because of their remarkable record of reliability. In this case, they are even less liable to suspicion because both roll and yaw are involved. It is difficult to conceive of a mechanical fault which would make both axes inactive and not produce some kind of spurious signals. From the above, it seems most probable that there was an open circuit in the wiring associated with the computer or the gyro.

Probable Cause

An open circuit in the wiring associated with the computer, or the roll-yaw gyro, plus an open in the synchronizing potentiometer for vane 4.

MISSILE 39

Performance

Preliminary stage appeared normal but main stage thrust failed to develop in the usual manner. The missile lifted after about six seconds of partial main stage. During the first few seconds acceleration was low but it increased smoothly to near normal at about 17 seconds. For the following six seconds the missile performance appeared normal. At 23 seconds the thrust started to decrease and was very low by 27 seconds. Steering was remarkably good during the powered flight with no evidence of instability until the start of the final decrease in thrust.

Data

Trajectory data, obtained from optics, indicated the following:

a. Missile velocity increased slowly and smoothly to a maximum of about 710 fps at 25 seconds.

b. Pitch program was present but was developing at nearly double the normal rate.

c. Between 6.6 and 23.6 seconds there was east movement at a relatively constant rate of about 4 fps.

Telemetry data showed the following:

d. Air Pressure

Started up at X – 8 seconds
Rose to 125 psi in approximately 0.5 second
Held level for about 0.5 second
Rose to 150 psi at X – 4 seconds
Rose on smooth curve to 460 psi at 17 seconds
Remained approximately constant at 460 psi to 23 seconds
Broke sharply at 23 seconds
Reached 340 psi at 25 seconds
Smooth curve to 25 psi at 65 seconds

e. Turbine Speed

Started up at X – 6.5 seconds
Rose slowly on smooth curve to 3900 rpm at 17 seconds
Held essentially constant to 23 seconds
Broke sharply at 23 seconds
Reached 3000 rpm at 24 seconds
Reached 1100 rpm at 38 seconds
Held 1100 rpm to 50 seconds
Broke to 0 rpm at 57 seconds

f. Combustion Chamber Pressure

Started up at about X – 5 seconds
Rose slowly on smooth curve to 220 psi at 17 seconds
Held at approximately 220 psi to 23 seconds
Sharp break at 23 seconds
Reached 140 psi at 24 seconds
Smooth curve to 0 psi at 36 seconds

Remarks

From the above data it is evident that the combustion chamber pressure increased in an abnormally slow manner because of the slow buildup in air pressure. In considering the unusual behavior of the air pressure, the following points should be noted.

a. It can be assumed that an adequate supply of high-pressure air was available at the start since the low-pressure air held the correct value some 31 seconds later.

b. It can be assumed that the pressure regulator was not directly at fault. The regulator was recovered in operative condition and actually passed a normal test after recovery.

c. It seems reasonable to assume that the abrupt drop at 23 seconds was caused by the same trouble that produced the slow buildup. This is supported by evidence that the cutoff relay (a9z) was not energized until X plus 55 seconds.

d. It can be assumed that the bleeder valves were at least partially closed. Tests have shown that if both bleeder valves are fully open, with no flow from the peroxide or permanganate tanks, the air pressure will hold at about 50 psi. In the case of this flight, the pressure built up to approximately 460 psi while peroxide and permanganate were being delivered.

Among the possible causes of abnormal air pressure are the following:

a. Foreign material acting as a restriction in the air system ahead of the tanks: this might account for a slow buildup, but it is hard to visualize a complete stoppage as indicated by the rapid drop at 23 seconds.

b. Bleeders not completely closed: a small opening might account for a slow buildup but would not cause a loss of peroxide. The steam generator would continue to operate until the air supply was exhausted. This would imply a gradual decline in air pressure, not an abrupt drop.

c. Leakage due to a mechanical break in the pressurizing or bleeder system: same comments as for b. above.

d. Leakage in peroxide tank or feed lines: this could account for a slow buildup. It would also involve the loss of peroxide which could produce an abrupt drop of both air pressure and turbine speed when the peroxide was exhausted. The most serious objection to this possibility is the fact that such a spray of peroxide in the tail could be expected to produce visible evidence. If it is assumed that the tank had a normal load of 126 litres and that the flow rate was normal at 1.4 litres for 31 seconds, then 2.6 litres per second must be sprayed into the tail to exhaust the peroxide at X plus 23 seconds. It would seem reasonable to expect, at the very least, a cloud of steam from the tail, starting before the missile lifted.

e. Peroxide tank not fully loaded. It appears that this condition accounts for both slow build up and abrupt end of thrust. The calibration curve for this steam plant shows that it required about 15 seconds to reach normal air pressure when the tank contained 72 litres of peroxide. For this launching the peroxide loading detail was made up largely of inexperienced men, so that the possibility of a personnel error existed.

Probable Cause

Peroxide tank not fully loaded.

MISSILE 40

Performance

The missile velocity was very close to the general average, although the missile was 1142 pounds over design weight. Steering was satisfactory but showed a west movement somewhat larger than normal. The pitch program was good. Up to 45 seconds the propulsion system was performing about 5 percent above normal. From 45 to 50 seconds there was a series of disturbances in the propulsion system. At 59.4 seconds the turbine started to overspeed and cut off the missile.

Data

Trajectory data, from optics and doppler, indicated the following:

a. Missile velocity was very close to the general average.

b. Pitch program was good

c. West velocity built up gradually to about 48 fps at 33 seconds. This velocity remained fairly constant to 45 seconds when propulsion disturbances started. From 46 to 51 seconds the velocity was to the east. Between 51 seconds and cutoff the velocity was again to the west, building up to a value of about 90 fps.

d. Film from telescope 3 showed that the jet flame decreased to about 30 percent of its normal length at intervals starting at about 45, 46, 47, 48, 49 and 50 seconds.

Telemetry data indicated the following:

e. There was no evidence of improper propulsion unit operation prior to 45 seconds. Approximate values are as follows:

Combustion chamber pressure	235 psi – about nine percent high
Low-air pressure	500 psi – about four percent high
Turbine speed	4070 rpm – about seven percent high

f. At 45.2 seconds a disturbance, lasting about 0.2 second, appeared on combustion chamber pressure. Almost simultaneously, disturbances appeared on low-air pressure and on turbine speed. It was not possible to determine the sequence in which the disturbance showed on the various channels due to reading errors and variations in end-organ response time. These disturbances were repeated on all three channels at about 45.2, 46.0, 47.1, 48.0, 49.0 and 50.0 seconds and consisted of two to four oscillations, at a frequency of 10 to 20 cps. The oscillations appeared to be centered about a value somewhat below the preceding steady-state value.

g. There was no indication of abnormal performance from 50 to 56 seconds.

h. At about 56 seconds the combustion chamber pressure dropped sharply from 235 to 157 psi. It remained at this level (with oscillation at about 16 cps) to 59.4 seconds when it started a decline to zero. Zero was reached at about 60.6 seconds.

i. During the period from 56 to 59.4 seconds, the turbine speed dropped only 110 rpm. At 59.4 seconds the turbine speed started up, reaching a peak of about 5200 rpm at 60.2 seconds. It commenced to drop rapidly shortly after 60.2 seconds.

j. From 68 to 206 seconds the turbine speed showed very unusual actions. The variations were too numerous to describe in detail, but the most interesting features were: (1) it stayed at about 4000 rpm from 127 to 195 seconds, (2) it reached a maximum of about 6000 rpm at about 180 seconds and (3) the start of its final decline (at 181 seconds) corresponds closely with the peak of the trajectory.

Remarks

The tendency of a turbine to run after cutoff has been noted occasionally. In some cases this could be attributed to leaky control valves. In this case the sharp decline at cutoff suggests that the 8- and 25-ton valves seated properly. The only other path for peroxide would be through the pressurizing line, and its associated check valve, to the permanganate tank. Steam generated there could flow through the generator to the turbine. The check valve in this line has been known to stick open in test. This appears to be the most probable reason for the erratic turbine action after cutoff.

Since telescopic data and telemetry data are in very close agreement, there is no cause to doubt that: (1) the propulsion unit performed as described above and (2) the overspeed trip on the turbine operated to cut off the missile.

Since the combustion pressure started to drop as the turbine speed started to rise, it is reasonable to assume that one or both of the pumps lost load. In view of the high turbine speed and the high combustion pressure, propellant exhaustion would be expected at about 60 seconds. The high-performance figures are supported by the fact that the missile maintained average velocity although overloaded about 1140 pounds.

The disturbances between 45 and 50 seconds and the reduced chamber pressure after 56 seconds remain to be explained. It seems reasonably certain that this trouble was caused by a loose connection to the auxiliary valve controlling the main alcohol valve.

Tests have shown that the alcohol valve can be closed part way against pump pressure if control air is applied to its piston. A short movement of the alcohol valve opens a by-pass line around the alcohol pump. Thus, the combustion chamber can be robbed of alcohol without a corresponding change in pump load. Tests have shown that under these conditions, the pump speed will decrease only about 128 rpm or about three percent. This corresponds remarkably well with the observed performance from 56 to 59.4 seconds, when the combustion pressure dropped 33 percent while the turbine speed dropped only 2.7 percent.

It is probable that some connection to the auxiliary control valve for the main alcohol valve was loose and was making intermittent contact to produce the disturbances noted from 45 to 50 seconds. The presumption is that this circuit opened up permanently at 56 seconds.

Probable Cause

An open circuit in the wiring to the auxiliary control valve for the main alcohol valve.

MISSILE 42

Performance

A casual inspection of the trajectory data would lead to the conclusion that the missile's performance was near normal. Velocity was about 5 percent below the general average. The pitch program angle was close to that desired. Azimuth steering to 22 seconds was exceptionally good with a total deviation at that time of 25 feet (east). From 22 to 53 seconds the azimuth angle remained rather constant at about four degrees east of north. Total deviation at 53 seconds was 400 feet. After 53 seconds the azimuth angle increased rather rapidly but did not become large enough to require cutoff by radio. Cutoff was by time switch in two steps. Reduced thrust occurred at 60.6 seconds and complete cutoff at 64.0 seconds. An inspection of telemetry data showed that vane 3 went to its center position at about 22 seconds.

Data

Trajectory data, obtained from optics, indicated the following:

a. Missile velocity was about 5 percent below the general average.

b. Pitch program angle was close to normal.

c. Up to 22 seconds, azimuth steering was excellent, with a total deviation at that time of 25 feet. From 22 to 53 seconds the azimuth angle remained nearly constant at about four degrees east of north. After 53 seconds the angle increased rapidly to approximately 20 degrees at burn-out.

d. Vanes 1 and 3 showed a moderate oscillation from lift. This appeared to be mostly roll with perhaps a little yaw. Vanes 2 and 4 were nearly steady.

e. At 21.5 second vane 3 was active. At 22.2 seconds, the next commutation point, vane 3 had returned to its center point where it remained for the rest of the record. Vane 1 continued to oscillate with possibly a slight increase in amplitude.

f. Vanes 2 and 4 were synchronized and showed some activity throughout the powered flight. They did not show any excessive or abrupt motions.

Remarks

It is somewhat remarkable that vane 1 was able to hold the missile in roll after the loss of vane 3. There is, however, a little cause to doubt that vane 3 was lost: (1) there was a trajectory disturbance at about the right time and (2) the telemetry channel showed a steady value of about 2.5 volts. If this value had been 0 or 5 volts, the telemetry would be suspected. But there are few ways in which the telemeter can fail and still show a middle voltage. Such a voltage could appear if the position-measuring potentiometer became disengaged from the vane. Recovery after impact showed the potentiometer still coupled to the vane. Therefore, it is reasonable to assume that vane 3 was actually lost.

Since vane 1 continued to operate in a very effective manner, it seems certain that the fault was not in a component which was common to vanes 1 and 3. Thus, the gyro and the command battery are eliminated. This leaves the mix-computer, the vane 3 servo and their associated wiring.

The servo was recovered after impact. The motor was broken away from the servo mechanism. All windings of the motor measured properly. The commutator looked good and there was no evidence of overheating. The brush holders were broken but this probably occurred at impact. The wire linkage between the control magnet and the control valve was broken but the nature of the break suggested damage at impact. The control magnet windings showed proper resistance and insulation values and the magnet action was good. The gear pump rotated with moderate freedom. In view of this inspection, it seemed unlikely that the servo was at fault.

Probable Cause

A computer failure or an open circuit in the control wiring.

MISSILE 45

Performance

The missile velocity was consistently about 17 percent below the general average. Otherwise, performance was good to 18 seconds. Up to this time the average east velocity was one fps. From 18 to 25 seconds the east velocity averaged seven fps. Starting at 25 seconds there was a sharp increase in east velocity reading a maximum of about 105 fps at about 51 seconds. The missile was cut off by radio at about 56 seconds.

Data

Trajectory data from Askanias indicated the following:

a. Missile velocity was consistently about 17 percent below the general average.

b. At 30 seconds the pitch program angle was very close to the desired value. After 30 seconds the pitch angle continued to increase but at a rate below normal. At the end of the program period, the pitch angle was 4.7 degrees compared to a nominal value of 7.0 degrees.

c. Up to 18 seconds the east velocity averaged one fps. From 18 to 25 seconds the east velocity averaged seven fps. Starting at 25 seconds, there was a sharp increase in east velocity which reached a maximum of about 105 fps at about 51 seconds.

Telemetry data showed the following:

d. Turbine speed and combustion pressure were about normal; low-air pressure was a few percent low.

e. Vane movements were small, up to about 18 seconds. Thereafter, some very fast movements took place. The amplitude of these movements was large. Apparently both roll and yaw correction were involved.

f. The telemetry commutator began to slow down at about 30 seconds. There was a gradual change to about 75 percent of its original speed.

g. Telemetry signals ceased at 48 seconds.

Wind data taken at 0600 Mountain Standard Time.

ALTITUDE feet above WSPG	APPROXIMATE TIME AFTER LAUNCHING seconds	VELOCITY fps	DIRECTION degrees
0	0	9	270
1000	9	20	260
4470	18	0	-
5100	19	20	250
8440	24	67	270
11950	28	66	280
17070	32	67	280
19440	34	75	270
21270	36	92	270
23340	37	135	270
24550	38	154	270
25540	39	153	270
27340	40	111	260
29440	41	89	260
31240	42	69	260
33380	43	53	260
35250	44	44	250
43130	48	91	280
44660	49	91	280

Remarks

There is a lack of agreement between the missile velocity (by trajectory data) and the propulsion unit measurements (by telemetry). The latter shows turbine speed and combustion pressure near normal, although the missile velocity appears lower than the average. Some reduction in velocity would be expected because the missile was 737 pounds overweight. Also a part of the discrepancy can be explained by probable errors in the telemetry readings.

The most probable cause of low thrust would be poor performance on the part of the pressure regulator. These devices have proved inconsistent in their operation.

The fact that the commutator began to slow down at 30 seconds suggests that the voltage of the power battery was dropping. This does not necessarily follow since mechanical binding may have developed in the commutator. The low-voltage possibility is strengthened, however, by the fact that the pitch program rate changed at about 30 seconds. The program device is known to be sensitive to low voltage and begins to operate erratically at about 24 volts. On the other hand, the servo motors were also sensitive to low voltage and they showed very fast movements up to 48 seconds (the end of the telemetry record).

It appears that a large part, if not all, of the east movement can be explained by the high winds above 5100 feet. It will be noted that there was very little deviation from the north line up to 18 seconds when the missile encountered the high wind velocities. From that time on, the missile velocity very obviously follows the wind velocity closely. There is, of course, a lag between changes in wind velocity and the missile response, but this is to be expected. The down-wind movement implies that the missile had very stiff control in yaw, otherwise it would tend to turn into the wind. This contradicts the low-voltage theory.

Probable Cause

Low thrust, due to poor regulator performance, plus high winds.

MISSILE 46

Performance

Missile velocity was about 5 percent below the general average. Movement of the missile to the north and to the east was above normal but can be easily accounted for by wind forces. Burning ceased at about 26 seconds.

Data

Trajectory data, from optics, indicated the following:

a. The missile velocity ran about 5 percent below the general average.

b. Movement to the north was above normal. At 25 seconds the apparent pitch angle was 5.5 degrees as compared to a normal value of 3.1 degrees.

c. Movement to the east was above normal. The east velocity gradually built up to about 25 feet per second at 25 seconds.

d. Telescopes reported that after burn-out, the rocket took about 1/4 revolution CW and then reversed, making about two turns CCW by the time it reached its peak.

Telemetry data indicated the following:

e. There was no evidence of any abnormal condition in the propulsion system for the first 25 seconds.

f. Low-air pressure, turbine speed and combustion pressure were near normal.

g. At 25.7 seconds the turbine speed started down in a typical cutoff decay. The earlier record was studied (frame by frame).and there was no sign of overspeed.

h. The pilot valves for the main valves were de-energized somewhere between 25.0 and 25.7 seconds (commutated channel – no record available for 2/3 of each second).

i. Pressure appeared in the control chamber of both main valves between 25.0 and 25.7 seconds (commutated channel).

j. The alcohol preliminary valve and its pilot (s1h) were in normal flight conditions at 25 seconds. By 25.6 seconds s1h was de-energized.

k. After cutoff, vanes 2 3 and 4 remained in their center positions. Vane 1 moved to an extreme position and remained there.

Remarks

The slightly low missile velocity was probably the result of the pressure regulator action. This device was not very consistent in operation and variations of 5 percent were common. No malfunction was indicated.

The fact that the north and east velocities were greater than normal does not prove that the steering system was at fault. The east movement in particular shows a very obvious relation to the wind velocity. From lift to 25 seconds, the east component of the wind velocity averaged 31 fps. During the same period the missiles' east velocity averaged about 10 fps,with a maximum of about 25 fps at 25 seconds.

There is little cause to suspect steering trouble. On the contrary, the down-wind drift indicates very stiff control in yaw.

In relation to premature cutoff, an important point is the fact that the turbine did not overspeed. This, together with the fact that all the main valves were operated to close at the same time the turbine speed started down, constitutes strong evidence that the cutoff was initiated by electrical command rather than a malfunction or abnormal condition of the main propulsion system. This could have been brought about by the pickup of A9z or the dropout of A6x (see Backfire, Vol II for detailed identification of A9z and A6x).

There is evidence indicating that the cutoff was by A9z rather than A6x. Operation of A6x cuts off the propulsion system but leaves the steering system operative. Operation of A9z cuts out both propulsion and steering. If cutoff had been by A6x alone, vanes 1 and 3 would be expected to show considerable movement since the missile rolled as described in d. This did not take place; therefore, it is probable that cutoff was by A9z.

In this missile there were three sources for energizing A9z: (1) overspeed trip circuit, (2) radio cutoff receiver and (3) ground cutoff relay A90z.

Since the turbine did not overspeed, cutoff from this source would come only through a mechanical or electrical failure. With reference to the overspeed device itself, an extensive series of tests were made to determine its susceptibility to vibration. A special test fixture was designed to allow both rotation and vibration simultaneously and a high-speed camera recorded its operation. From these tests it was apparent that the overspeed device was not sensitive to vibration. This does not, of course, eliminate the possibility of a mechanical failure.

The ARW-37 type of cutoff receiver had been subjected to thorough tests with reference to both vibration and interference. These tests indicated that this receiver was highly reliable. There was no evidence suggesting that the receiver was the source of cutoff.

The contacts of ground cutoff relay, A90z, were fed through contacts of take-off relay A7y. If A7y functioned properly, there should have been no voltage on the contacts of A90z during flight. This means that both A7y and A90z would have had to close contacts simultaneously to energize A9z. These two relays are of different types and the probability of simultaneous closure due to vibration is slight.

Probable Cause

The energizing of cutoff relay A9z by some unknown mechanical or electrical failure within the control system.

MISSILE 50

Performance

Missile performance appeared entirely normal up to 43.4 seconds; missile velocity was within about 1 percent of the general average and the steering was good. The pitch program was very close to the desired value and deviation from the north-south line was not great. At 43.4 seconds the combustion chamber pressure dipped to about 69 percent of its previous value for approximately one second. A second dip occurred at 48.4 seconds. At 51.7 seconds this pressure dropped to about 66 percent of its original value and remained at the lower figure to the end of burning (62.5 seconds). The steering remained good to burn-out and there was no need to cut off the motor by radio.

Data

Trajectory data, obtained from optical instruments, indicated the following:

a. From 10 to 43.4 seconds the missile velocity remained within about 1 percent of the general average.

b. The pitch program was unusually good.

c. West velocity built up gradually to about 15 fps at 26 seconds and then gradually decreased to about three fps at the time of the first disturbance. The deviation at 43.4 seconds was 271 feet (west) and at 62.6 seconds (burn-out) was 158 feet (west).

d. Telescopic photographs show the following:

SECONDS	OBSERVATION OF JET
43.35	short for one second
48.50	fades for one second
49.5 to 51.7	detached by 1/2 missile length
51.8	grows very dim
58.3	back but weak
58.35 to 59.2	not visible on film
59.3	back but weak
62.3	very intense
62.55	no longer visible on film

Telemetry records were reasonably good and provided much valuable information. Channel 27 failed to record for reasons unknown. This was particularly unfortunate since this channel monitored the control commands to the two pilot valves controlling the two main propellant valves, the probable source of the propulsion difficulty. Telemetry records showed the following:

e. The turbine speed reached a steady state value of about 3900 rpm at about one second after lift and held this value without appreciable change to about 58 seconds. From 58 to 61.6 seconds the speed oscillated slightly. The turbine started to overspeed at 61.6 seconds, reaching a maximum of about 5450 rpm at 62.15 seconds. The speed had dropped to zero by 65 seconds.

f. From lift to 34 seconds, the low-air pressure remained constant at about 474 psi, approximately three percent above the intended value. Between 34 and 35 seconds, the pressure rose to about 506 psi (approximately 10 percent high) and remained fairly steady at this value to the end of burning.

g. Combustion chamber pressure varied as follows:

TIME AFTER LAUNCHING seconds	OBSERVATION	PRESSURE psi
3	reaches steady state of about	270
16	completes a gradual rise to	290
43.4	dip starts (minimum value)	200
44.5	back up to	290
48.4	dip starts (minimum value)	200
49.7	back up to	290
51.7	dips to	192
57.8	still at	192
57.85	severe oscillation starts	
61.65	starts final drop	
61.90	has completed drop to about	0

h. The main power supply voltage remained essentially constant at approximately 27 volts throughout the powered flight.

i. Summary of major events

TIME AFTER LAUNCHING seconds	OBSERVATION
3.0	Essentially steady-state conditions reached
43.4	CCP (combustion chamber pressure) dips 31 percent (change in turbine speed barely perceptible)
43.5	Pressure appears on oxygen main valve (95 psi or more) (was all right at 41.8 seconds which was last commutation)
44.2	CCP starts back up, fast oscillation
44.43	Pressure on oxygen main valve gone (below 95 psi) (note: possibly earlier, this was next commutation)
48.31	Pressure on alcohol main valve (170 psi or more) (was below 170 psi at 48.30 seconds)
48.45	CCP starts dip of 31 percent (change in turbine speed barely perceptible)
49.36	Pressure still on alcohol main valve (end of commutator segment)
49.5	CCP starts up, severe bump in oxygen pump inlet pressure
50.1	Pressure off both main valves
50.4	Oxygen pump pressure at zero, remains at zero, oxygen tank pressure satisfactory
51.7	CCP drops about 34 percent and remains at this value
51.93	Pressure on alcohol main valve
52.27	Oxygen tank pressure down to zero, remains down thereafter
57.85	CCP starts severe oscillation, turbine speed indicates oscillation
58.50	Pressure is now on both main valves (pressure on alcohol valve only at 57.8 seconds)
61.65	CCP starts final drop, turbine speed starts to increase
61.90	CCP is essentially zero
62.15	Turbine speed reaches maximum of about 5450 rpm
65.00	Turbine speed is essentially zero

Remarks

The steady-state combustion chamber pressure was recorded as being approximately 32 percent above the desired value. There is reason to believe that the actual value is in error. In the first place, this is not in agreement with the low-air pressure and the turbine speed (in reasonable agreement with each other, both being from 5 to 10 percent high). In the second place, the missile velocity was very close to the general average, indicating that there was no large increase in chamber pressure or thrust. In the third place, such a chamber pressure would have required a large increase in propellant flow rate, resulting in very early exhaustion of at least one propellant.

Although the actual magnitude of the combustion chamber pressure is believed to be in error, the record is very useful since it does show the changes which took place. There is considerable reason to trust the relative values since they are confirmed by the telescopic records.

Important information is available from the record of channel 28 (used to record the presence or absence of control pressure on the main propellant valves). If full control pressure is applied to the control chambers, the valves will move toward the closed position against pump pressure, but will not close completely. Calibration stand tests with water instead of the usual propellants, were made to obtain information on the effects of applying control air to the main valves. Since the combustion chamber pressure was simulated and the effects of oxygen evaporation were not present, the tests were not wholly representative of flight conditions. It is believed, however, that, with certain corrections, they present a fair approximation of the effects to be expected in flight. The tests indicate that the application of control pressure to either valve individually, or to both valves simultaneously, will result in a change of turbine speed of less than 5 percent. Under the same conditions, the drop in combustion pressure will be somewhere between 20 and 50 percent.

From the summary of major events, part i. above, it will be noted that each drop in combustion pressure was accompanied by the appearance of pressure on one, or both, of the main valves. It is conceivable that the pressure on the oxygen main valve might have been produced by the leakage of lox past its seal. There are, however, several reasons for discounting this possibility. One reason is that it would require a tremendous leakage (a magnitude never experienced before) to build up substantial pressure against a special vent of very large capacity. Second, if 43 seconds were required for a leak to build up a pressure of 95 psi, it would hardly be expected to double or triple that pressure in one or two seconds: it is reasonably certain that a few hundred psi would be required to produce the observed effect on combustion chamber pressure.

At 48.31 seconds, pressure appeared on the alcohol main valve alone. This could hardly have been caused by anything other than the operation of its associated pilot valve, S2h. This pilot valve, when deenergized, applies air pressure to force the main valve toward the closed position. It is highly probable that an intermittent contact in the circuit of the pilot valve was responsible for the partial closure of the alcohol main valve, with a resulting drop in combustion pressure. The oxygen main valve is controlled by a similar pilot valve, O3h, located on the same block with S2h. The control wires for both pilot valves are brought out of the main distributor on the same plug (V). Likewise they are brought out of the secondary distributor on a common plug (29). If either of these plugs should be loose or defective, intermittent contact might be expected in both valve circuits.

It is unlikely that either plug V or plug 29 was loose. Special measures were taken to insure against this type of trouble. Plug V was secured in place by a strip of rubber backed by a heavy steel strap. Plug 29 was held in place by a spring-loaded latch, which was further secured by safety wire. The probability of a defective plug is greater. This is particularly true in the case of plug V. Little trouble was experienced with this type of plug as made in Germany, but the US-made copy showed a tendency to break. The breaks followed a fixed pattern. Almost invariably the break ran through three adjacent pins, such as 3-13-23 or 6-16-26, located parallel to the short dimension of the plug. The probability of such a break is suggested by the fact that the control circuits for O3h and S2h used adjacent pins 9 and 19.

Probable Cause

Intermittent contact in the control circuits for pilot valves O3h and S2h (possibly a broken plug V in main distributor).

MISSILE 52

Performance

Missile performance appeared normal up to 8.0 seconds. The velocity was slightly above the general average and the steering appeared to be satisfactory. Unless there is some serious steering trouble, it is not possible to evaluate the steering performance during the first few seconds. It can be said, however, that no steering difficulty was apparent. At 8.0 seconds there was a violent explosion in the tail. This caused trouble in the steering system but showed very little effect on the propulsion system. Thrust continued to approximately 22 seconds when the propulsion unit was shut down by radio.

Data

Optical equipment provided information as follows:

a. The missile velocity was about three percent above the general average.

b. As well as could be determined, the steering was satisfactory.

c. Excellent pictures of the explosion were obtained. A 96-frame-per-second film shows that the explosion started near the bottom of fin 3. One frame shows the missile in normal flight. The next frame shows a bright spot near the bottom of fin 3. The next frame shows gas, vapor or smoke being blown from a number of openings in the tail. Three frames later a large hole is visible in fin 3 at the point where the bright spot appeared four frames earlier.

An excellent telemetry record was obtained but its usefulness was somewhat impaired by the fact that the calibrating device failed to function and there were no calibration marks on the record. This made it impossible to obtain accurate values but approximate values were obtained. They showed that all monitored quantities were very close to the desired values up to the instant of the explosion. No abnormal conditions could be detected. An accurate value of turbine speed was obtained from a geared contact-making device which was independent of the calibrating device. Turbine speed was recorded as 3916 rpm, within three percent of the desired value.

Telemetry offered the following additional information:

d. There was no detectable change in turbine speed after the explosion.

e. The record shows that the combustion chamber pressure dropped at the instant of the explosion to about 76 percent of its previous value. This may have been the result of a damaged pressure gage, since the outlet pressure of the alcohol and the oxygen pumps show no detectable change from their previous values.

Remarks

The two probable sources of a violent explosion in the tail are hydrogen peroxide and alcohol. The fact that the steam plant continued to operate near capacity for 14 seconds after the explosion means that no large amount of hydrogen peroxide could have been discharged into the tail. It is therefore highly probable that the explosion was caused by an alcohol leak. Since the propulsion unit performance was normal, or slightly above, it is unlikely that there was a large rupture in the alcohol system. It appears probable that there was a relatively small alcohol leak which gradually built up an explosive concentration in the tail. There is no further information to aid in locating the point of the leak or the source of the ignition.

Probable Cause

A relatively small alcohol leak, resulting in an explosive concentration in the tail, ignited from some unknown source.

MISSILE 54

Performance

Preliminary stage was very good. When main stage was energized, the turbine started and thrust increased but the missile did not lift. The appearance of the main-stage flame was not normal. An unsuccessful attempt was made to cut off the motor. After about ten seconds of burning, the missile lifted. Acceleration was very low. Fortunately the missile was stable. The powered flight continued up to 44 seconds when the combustion chamber pressure started to drop reaching zero at about 50 seconds.

Data

Optical instruments provided information as follows:

a. Acceleration was low throughout the powered flight with a maximum of about 16 ft per sec^2 at about 43 seconds.

b. There was definite evidence that the pitch-north movement of the missile was increasing, indicating that the pitch program was operative.

c. The missile was remarkably stable in yaw, with a reported maximum excursion of about one degree.

Telemetry records were good to about 56 seconds. Unfortunately, the commutator failed and valuable information was lost. Good records were obtained in alcohol pump outlet pressure, turbine speed, combustion chamber pressure, alcohol flow, oxygen flow and vane positions.

Telemetry provided information as follows:

d. Alcohol pump outlet pressure started up at -8 seconds, reached 234 psi at -6 seconds and remained constant to 50 seconds (normally this pressure should be about 300 psi).

e. Turbine speed (by counter, should be accurate) started up at -9 seconds, reached 3978 rpm at -5 seconds, and remained constant to 42 seconds, at which time it started to overspeed. From 45.2 to 53.35 seconds the value was 5886 rpm.

f. Combustion chamber pressure started up at -8 seconds, reached 112 psi at -6 seconds and remained constant from -6 to 44 seconds. It started down at 44 seconds and reached zero at 50 seconds.

g. Alcohol flow was approximately 170 pounds per second (37.7 percent above the nominal value).

h. Oxygen flow had an average value of about 60 pounds per second (39.4 percent of the nominal value).

i. Vanes 2 and 4 were synchronized and showed remarkably little motion during the flight. There was a gradual movement of these vanes away from their zero position. This amounted to about 10 degrees in 39 seconds.

Recovery was exceptionally good. The entire propulsion unit and much of the midsection were returned virtually intact. Information from recovered equipment was as follows:

j. The main distributer was recovered in fair condition. A careful wire check indicated that the wiring to relay A9z was correct and continuous.

k. The oxygen tank was recovered with the oxygen-flow float still intact on its guide wires.

l. The orifice in the oxygen line was rechecked and found to be 125 mm, which was the diameter of the oxygen pipe.

m. The entire oxygen system was checked for any obstruction to flow and none was found. The search was very complete, even to the extent of removing the oxygen rosettes from the motor head. They were absolutely clean and open.

n. The oxygen pump was recovered in good condition and there was no evidence of anything wrong.

o. The heat exchanger check valve was recovered in good condition. After impact, a check showed that it would open at 38 psi.

p. The main oxygen valve was recovered in excellent condition. It was tested before disassembly. The test showed the valve would start to open at 80 psi and would be fully open at 100 psi (at room temperature). The valve was then taken apart and inspected; no abnormalities were found. The valve was reassembled and placed in a cold-test fixture; lox was applied to the top for two hours. Under this condition, the valve would start to open at 100 psi and would be completely open at 150 psi. Next, about 1/2 cup of water was dumped on top of the valve before lox was applied. In this case the valve opened fully at about 200 psi. Next, moisture was allowed to condense on all surfaces of the cold valve before lox was applied. In this case the valve opened at about 250 psi.

q. The switch battery was recovered in good condition. Both valves operated satisfactorily (electrically and pneumatically).

Remarks

It is clearly established that the flow from the lox tank was only about 40 percent of its nominal value. The telemetry record of lox flow is supported by the combustion chamber pressure and the alcohol flow. Since the flow was measured in the tank, there is no cause to suspect that the low flow at the motor was due to a break in the lox piping.

Assuming no break in the lox piping, the low flow must have been due to incorrect pump operation or to some restriction in the lox system.

It has been established that: (1) the pump was rotating at a value slightly above normal and (2) there was no visible defect in the pump. The only remaining probability of pump trouble would be cavitation. It is probable that the pump would cavitate if the lox tank were not pressurized. It is known, however, that the tank was pressurized prior to preliminary stage. This means that the tank would have had to lose pressure at, or near, main stage. This could result from the loss of the ground air supply or from a malfunction of its control valves. This is highly improbable, however, because in such a case improvement would be expected when the heat exchanger became operative.

Loss of lox tank pressure would result if the lox vent valve opened. The valve was observed to close by two witnesses. Further, the time required to pressurize the tank originally was normal. It is therefore established that the vent operated normally prior to main stage. There remains the possibility that some malfunction in the main stage switching reapplied air to open the vent. This is improbable because, in such a case, the vent should have been reclosed by spring pressure at lift. Thereafter improvement should have been noted.

Pump cavitation could have been caused by a break at any point in the tank pressurizing system. The result would be the same as the opening of the vent valve. This is one of the more probable causes of the failure.

There were three major possibilities of a restriction in the lox system: (1) foreign material (2) incorrect lox orifice or (3) a partially opened lox valve. A careful search revealed no evidence of any foreign material. A recheck after impact showed that the lox orifice was of the same diameter as the lox pipe. This eliminated the possibility of an error in calibration calculations. In view of these points, the lox valve remains as the only probable source of restriction.

The lox valve could produce a restriction to normal flow in two ways: (1) it could fail to open fully or (2) it could be operated to partially reclose. Tests described above showed the valve to be in excellent operating condition even after impact. The last two tests were made under extreme conditions that could hardly be expected to exist at the time of launching. Failure to open fully could be considered as possible but improbable.

A malfunction of the pilot valve for the main lox valve could apply air to the control chamber of the main lox valve. This would tend to close the lox valve part way and would cause a large reduction in flow. The pilot valve, a part of the switch battery, was recovered and tested. Even after impact it operated in a satisfactory manner. This does not prove, however, that there was not a malfunction inthe electrical circuit which controls that valve.

There is another factor which raises considerable doubt that the lox valve tried to close. In the original V-2 system the control chamber of the lox valve was vented during the powered flight. Under certain circumstances the original vent was too small and a second vent (many times the capacity of the original) was added. For reasons of timing the pilot valve for the second vent was not connected in parallel with the pilot valve for the lox valve. Instead, it was in parallel with the pilot for the alcohol valve. Thus the added vent should be open when the alcohol valve was open. Since there is ample evidence that the alcohol valve was wide open, it is probable that the added vent was open. If the added vent was open, application of control air to the lox valve would not be expected to produce appreciable movement of the lox valve.

In addition to the low lox flow, there were three failures, apparently electrical, to be explained: (1) the telemetry commutator failed to operate, (2) the ground cut-off circuit failed to cut off motor operation and (3) the overspeed device failed to shut down the propulsion system.

The failure of the commutator may be unrelated to the other failures. There had been considerable bearing trouble with these commutators and further trouble of this nature would not be surprising.

The ground cut-off failure also may be unrelated. After the launching, the fin cut-off plug was found to be out of its holder. It was in place prior to launching and it is probable that it was blown out after the missile lifted, but this is not a certainty.

As stated in section j. the wiring to cut-off relay A9z was re-checked after impact and appeared to be in order. Some other failure must have taken place since A9z should have been energized when the turbine speed exceeded 5200 rpm.

There is one possible explanation for all the observed failures. The various devices in the missile showed considerable variation in the minimum voltage required for operation. It is conceivable that there was a particular value of resistance between the power battery and the bus which lowered the bus voltage to a critical point where some devices would operate and others would not. Such a voltage might be sufficient to hold the alcohol side of the switch battery but not enough to hold open the lox valve and the added vent. It would be assumed that the voltage was too low to run the commutator or to pick up A9z at overspeed. Low battery voltage could produce the same result but a battery that had dropped that low could hardly be expected to carry the missile load for an added 55 seconds. Although the resistance idea could expiain all the observed effects, it is difficult to accept because of the very narrow range of resistance which would satisfy the conditions.

Probable Cause

An opening in the pressurizing system of the lox tank, resulting in the loss of tank pressure and cavitation of the lox pump.

MISSILE 55

Performance

Preliminary stage developed normally. Main stage was energized and the plugs dropped. Shortly thereafter there was a fairly violent explosion in, or above, the control chamber. After an instant the missile toppled to the ground. At, or shortly after impact, there was a violent explosion followed by several other explosions of varying intensity.

Data

There was very good camera coverage. One high-speed camera, located 1000 feet to the east, provided particularly useful information. A study of various films disclosed the following:

a. The missile definitely lifted, perhaps as much as six inches.

b. It was not possible to determine whether the explosion occurred just before or just after lift. It is clear, however, that it occurred within a few hundredths of a second of lift.

c. One 96-frame per second camera caught the very start of the explosion. In one frame the missile is absolutely normal. In the next frame bright flashes are present. Two of these flashes are certainly at TNT locations. This frame also shows a bright streak where prima cord ran from the TNT to the nose cone.

Remarks

There is the possibility of an alcohol explosion, but this seems highly improbable. First, great care was taken (as always) to insure that no alcohol was spilled in the missile. Second, an alcohol explosion would be expected to produce visible damage to the midsection. Excellent photographs show absolutely no distortion of the midsection. Third, it would be necessary to assume that the alcohol explosion set off the TNT since photos clearly show that the TNT was detonated. Fourth, it would be a most remarkable coincidence for an alcohol explosion to occur at the precise instant that the protective short was removed from the TNT.

If it is assumed that the explosion was initiated by electrical means, there is a choice between induced potential and the application of voltage by direct contact.

It is highly improbable that the explosion resulted from induced potential. The short-circuiting wires were the only wires of any appreciable length. These were made up in a separate cable. Its principal exposure was a run of about 20 feet parallel to: (1) the 500 cycle potentiometer supply or (2) the 28 volt servo supply. The former was an unshielded pair carrying about 0.14 amperes at 40 volts, 500 cycles. The latter was an unshielded pair carrying the servo power at 28 volts d-c. Probably the worst surge on the 28-volt line would come from an open in the servo feed, resulting in a drop from about 30 to 0 amperes. Evidence indicates that this did not happen.. It does not seem probable that induction from either of the above sources would set off a squib of five ohms requiring a minimum of 0.050 amperes. The normal squib requires 0.10 ampere so the 0.05 figure is conservative. In addition two such squibs are connected in parallel. The probability of pick-up from some high-frequency source seems small.

In considering direct contact, two possibilities exist. One is that movement of the rocket removed the protective short circuit and allowed the squib to fire. The other is that movement of the rocket produced a contact which caused the squib to fire.

In either of the above cases there is the remote possibility that rocket vibration disturbed the wiring in such a manner as to produce direct contact. This would require a double fault that would place positive polarity on one wire and negative on the other. This is too freakish to warrant much consideration.

There is always the possibility of the existence of some permanent-type connection which could apply voltage to the squib circuit. Under this classification would come sneak circuits, wiring errors and permanent short-circuits between wires. The chief objection to this type of fault is the fact that it would have to be timed perfectly. If such a connection did exist, it would have to be so located that it was effective for only a short period during some specific switching sequence. Otherwise it would be detected during tests conducted for that purpose. If the short-duration feature is accepted, then the time-of-occurrence is limited to a fraction of a second before or after lift. This limitation does not remove the possibility of such a connection, but it certainly reduces the probability.

One other possibility has been considered. The protective short-circuit was completed through the pull-away plug. This plug has butt-type contacts. The pins are individually spring loaded and have a follow-up of about an eighth of an inch. If the missile had moved horizontally about 1/2 inch before it lifted 1/8 inch, the short-circuiting pins could have touched certain energized contacts. These contacts were so arranged that the missile would have to move in one specific direction (within narrow limits) to apply potential to the shorting pins. In a clean, fast lift the probability would be low. If, however, the missile bobbled about on the stand a few times prior to final lift, the probability increases.

None of the above possibilities is particularly attractive and none is supported by additional evidence. In such a case, the least complicated has the most appeal.

Probable Cause

The squib short-circuiting pins made contact with energized points on the ground plug as the missile thrust fluctuated a bit prior to final lift.

MISSILE 57

Performance

Performance appeared normal up to 15.5 seconds. The missile velocity was about 10 percent below the general average but was very close to the average for missiles of comparable weight and contour. Steering was good, with a total deviation at 15.5 seconds of five feet. Trajectory data indicates that the pitch program was developing. At 15.56 seconds there was a large explosion in the tail section and small pieces were seen to leave the missile. This explosion appears to have damaged the steering system since the missile had begun to tip south by 16 seconds. Although the jet showed signs of being disturbed, thrust continued up to about 18.5 seconds. The jet flared up at 18.25 seconds and ceased abruptly at 18.5 seconds. At that time there may have been a second explosion in the tail. There was another explosion of considerable magnitude at 19.5 seconds, after which the missile was enveloped in flame.

Data

Trajectory data provided the following information:

a. The missile velocity was normal for a missile of its type, with a value of 501 fps at 15 seconds.

b. The pitch program was developing at about the normal rate.

c. The east-west deviation was small, five feet at 15 seconds.

Good telemetry records were obtained at all three ground stations. Unfortunately, their value was greatly reduced by the fact that the ground reference (zero volts) channel was erratic throughout the entire flight. For this reason the telemetry data is not considered reliable as far as actual values are concerned. The records were useful, however, in that they indicated that all propulsion unit measurements were near normal and that no disturbances took place prior to the first explosion. The turbine speed was monitored by a revolution counter in addition to the usual tachometer. Since the counter produced pips, rather than a proportional voltage, an accurate determination of turbine speed could be obtained. This indicated that the average speed was 3900 rpm compared to a desired value of 3910 rpm.

Remarks

Neither trajectory data nor telemetry data gave an indication of any abnormality in the propulsion system prior to the explosion. Certainly there was no rupture of sufficient size to have any appreciable effect on the thrust. It therefore appears that there must have been a small alcohol leak which eventually built up an explosive concentration in the tail. There is no evidence to aid in determining the location of such a leak or the source of ignition. The xx explosions and other events which followed the first explosion are to be expected under such circumstances and do not appear to offer any evidence concerning the origin of the explosion.

Probable Cause

A relatively small leak in the alcohol system, resulting in an explosive concentration in the tail, ignited from some unknown source.

BUMPER 2

Performance

The Missile velocity was about 10 percent low compared to the general average for missiles of standard V-2 contour. Steering was good up to about 25 seconds when some type of trajectory disturbance was indicated. From 25 seconds to cut-off the steering appeared to be somewhat erratic but acceptable. The motor was cut off by turbine overspeed at about 33 seconds.

Data

Trajectory information, from Askania records, indicated the following:

a. Missile velocity was about 10 percent low compared to the general average for missiles of standard V-2 contour.

b. Pitch program was developing in a normal manner to 24 seconds when the pitch angle started to decrease. The angle reached 0.3 degree at 26 seconds, after which it started a rapid increase toward normal. At cut-off the angle was about 2.4 degrees.

c. Azimuth steering was good with an average east velocity of about 2.5 feet per second up to 25 seconds. From then to cut-off there was little change in velocity.

Telemetry data indicated the following:

d. The steering system was working hard but the missile was under control.

e. Up to 28 seconds the propulsion system performance was completely normal with measured values as follows:

Turbine speed	3840 rpm
Combustion Pressure	213 psi
Low-air pressure	473 psi

f. Combustion pressure and low-air pressure readings were lost at 28 seconds due to the failure of a potentiometer.

g. The turbine started to overspeed at about 33 seconds. It reached a peak speed of 4800 rpm a few tenths of a second later. The speed then decreased in the manner typical of overspeed trip.

Remarks

All available evidence indicates the loss of certain telemetry readings had no connection with the turbine overspeed. There is much evidence to indicate that the telemetry failure was caused by an overloaded potentiometer.

Four possible causes of turbine overspeed are suggested:

a. a large rupture in the propellant piping system,

b. the exhaustion of one or both propellants,

c. cavitation of the oxygen pump due to loss of pressure in the oxygen tank,

d. the closing of the preliminary alcohol valve.

It would be expected that a large rupture in the propellant piping would result immediately in an explosion, a fire or at least a large cloud of vapor. Optical conditions were favorable and four telescopes had the missile in view at the time of cut-off. Since no evidence of a break was noted, that prospect seems poor.

Assurance that the alcohol tank was full at lift was checked by two independent means. The oxygen tank was filled until overflow occurred. The oxygen boil-off time was only 95 minutes. It is reasonably sure that both tanks were nearly full at lift. It is hardly conceivable that one of the propellants could have been pumped at twice the normal rate. It is therefore highly unlikely that propellant exhaustion took place at 33 seconds.

It is unlikely that the oxygen tank lost any appreciable pressure through the vent valve since this valve is held closed by adequate spring pressure. This still leaves the possibility of a leak in the pressurizing piping or the failure of the heat exchanger. Since this system consists mainly of simple, rugged piping, the probability of failure is relatively low.

A more probable cause of turbine overspeed is premature closure of the preliminary alcohol valve. Since both air pressure and electrical power are required to keep this valve closed, it is one of the more vulnerable components of the propulsion system. The control circuit for this valve includes one relay contact, one connector, one pilot valve and a number of wiring junctions. The opening, or failure, might be anyplace within this system. No data is available to aid in a closer determination of the source.

Probable Cause

Closure of the alcohol preliminary valve caused by a failure in the circuit controlling this valve.

BUMPER 4

Performance

The flight appeared normal in every respect to 28.5 seconds. Missile velocity was very close to the general average and the steering was good. At 28.5 seconds it appeared that a tail explosion caused the jet to broaden, the telemetry record to go bad, the beacon signal to disappear and the servo signals to increase to near maximum. These spurious signals drove the jet vanes hard over, causing the missile to execute a fast turning motion. Impact was at approximately 130 seconds.

Data

Trajectory data indicated the following:

a. Missile velocity was normal, sonic velocity was reached at about 25 seconds.

b. Steering was good up to 28.5 seconds. East deviation at that time was only 72 feet and the pitch program was developing normally. The telescope data indicated that the missile showed no sign of roll.

c. The jet flame showed a disturbance starting at 28.5 seconds. At that time the jet broadened until it appeared wider than the fins.

d. In the first telescope picture showing a jet change, two bright specks are visible at, or near, the junction of the tail and the midsection. These do not appear in the next frame (16 frames per second) although the jet becomes longer and broader.

e. In the third frame the jet begins to decrease and appears normal by the tenth frame. The telescope record also shows that the missile had reached the vertical by the tenth frame. In frame 17 there is clear evidence that something is streaming from the forward part of the tail. By this time the rocket showed considerable pitch south and the tail appeared to be burning. By frame 35 the missile is about horizontal.

Telemetry data showed the following:

f. Up to 28.5 seconds all monitored quantities gave good records with the exception of combustion chamber pressure which ceased to give useful data shortly after lift. All values appeared absolutely normal up to 28.5 seconds.

g. The telemeter itself survived the disturbance at 28.5 seconds but it appeared that all pressure-measuring end-organs were damaged by the disturbance. Signals continued to be recorded occasionally from the more rugged end-organs such as pressure contacts, vane-position potentiometers and the turbine speed tachometer, up to 30.25 seconds when all signals disappeared.

h. The turbine speed remained essentially constant to the end of the record.

i. At 28.5 seconds all four servo signals increased in 0.03 second to near maximum values and the jet vanes immediately started to move toward their extreme positions.

j. There was no evidence that any pressure contact operated, or that any solenoid contact operated or that any solenoid valve was improperly energized.

Remarks

All the evidence points to a tail explosion. First, the appearance of trouble was sudden and occurred simultaneously in a number of independent forms, such as the change in the jet, the loss of the beacon signal, the disturbance in the telemetry and the increase in the servo signals. All these suggest a severe shock. The momentary appearance of bright spots at the junction of the midsection and the tail supports the idea of a tail explosion. The photographic evidence of a liquid or gas flowing from the tail implies a broken propellant line. The fact that the trouble appeared in the trans-sonic region suggests that a break may have been caused by the vibration which is expected at that time. In view of the above, it appears probable that there was a break in the alcohol piping. There is no data to aid in the location of the precise point of the break or the source of ignition.

A break in the alcohol piping which resulted in an explosive mixture in the tail, ignited by some unknown source.

BUMPER 6

Performance

Missile performance was normal up to 47.5 seconds. The velocity was very close to the general average. Although there was no north movement until about 19 seconds, this can be explained readily by the fact that there was an appreciable wind component to the south while the average pitch angle to the north during this period was about 0.2 degree. Westward deviation reached a maximum of about 30 fps at about 44 seconds, but this can also be explained by the west component of the wind which reached a maximum of about 90 fps at approximately 40 seconds. At about 47.5 seconds some malfunction apparently shut down the propulsion unit.

Data

Optical data indicated the following:

a. Missile velocity ran very close to the general average up to the point of shut off.

b. North movement was apparent at about 19 seconds. There is evidence that the pitch program was developing.

c. West deviation reached a maximum of about 30 fps at about 44 seconds. Total deviation was about 220 feet at shut-down.

Telemetry records showed the following:

d. Prior to shut-down there was no evidence of any type of malfunction. All monitored quantities were normal.

e. At 47.56 seconds, the auxiliary control valves (03h and S2h) for the main propellant valves were energized.

f. At 47.66 seconds, pressure appeared in the control chambers of the main propellant valves.

g. At 47.75 seconds the turbine speed started to drop to zero. An examination of the record showed no overspeed prior to the drop.

Remarks

The action described in e, f and g. above could have been caused by the drop-out of relay A6x. The telemetry record showed, however, that the inverters were de-energized at the same time that the propulsion unit was shut down. This indicates that at least one "back" contact of relay A9z opened at this time. It is therefore reasonable to assume that the drop out of A6x was caused by the opening of another back contact of A9z.

The opening of the A9z contacts (the cut-off relay) may have been caused by vibration. There is no direct evidence to prove or disprove this possibility. This relay does, however, have a good record with respect to vibration. Further, it gave no trouble during the trans-sonic period when greater vibration might be expected.

Aside from the possibility of vibration effects on A9z, there were four circuits connected to energize A9z under certain circumstances: (1) turbine overspeed switch, (2) radio cut-off receiver, (3) ground cut-off relay A90z and (4) a circuit concerned with experimental equipment. Since the turbine did not overspeed, circuit (1) was not responsible unless some mechanical or electrical failure occurred. Extensive tests of the overspeed device itself have indicated that it is not sensitive to vibration.

It was reported that the radio cut-off transmitter was not actuated. The cut-off receiver (ARW-37) has demonstrated in tests that it is not sensitive to vibration. No other evidence points to the cut-off receiver.

The contacts of ground cut-off relay, A90z, are energized through contacts of take-off relay A7y. If A7y functioned properly, there should have been no voltage on the contacts of A90z during flight. This means that both A7y and A90z would have had to close contacts simultaneously to energize A9z. Since these two relays are of entirely different types, the probability of simultaneous closure due to vibration appears to be slight.

It is highly improbable that circuit (4) caused the trouble. There is clear telemetry information that it was not at fault.

Probable Cause

The energizing of cut-off relay A9z by some unknown mechanical or electrical fault within the control system.

BUMPER 7 AND 8

Performance

The experiments carried on these missiles called for a relatively low trajectory, with a separation angle of approximately 20 degrees from the horizontal. This trajectory required a relatively rapid turn during the powered flight of the V-2. Both missiles made the turn successfully and the general performance appeared good. A closer examination of the trajectory data showed, however, that the program had been greater than desired.

Data

Trajectory data showed the separation angle for Bumper 7 to be approximately 10 degrees and that for Bumper 8 to be about 13 degrees.

Remarks

The fact that the two trajectories showed the same type of discrepancy indicated a systematic rather than a random fault. Since it seemed highly improbable that the pitch device itself would fail in such a fashion as to increase the program, precession of the pitch gyro was suspected. Since the pitch gyro circuits had been modified to obtain a much larger than normal program, these circuits were among the first investigated. This investigation showed up a "sneak circuit" which caused the erecting motors of the pitch gyro to be energized after take-off. This in turn caused a precession which operated to increase the program angle. This fault appeared to answer fully the observed discrepancy.

Probable Cause

A "sneak circuit" which caused the erecting motors of the pitch gyro to be energized after take-off.

MISSILE SPECIAL

Performance

In general, missile performance was normal up to about 36 seconds. Up to the end of burning, the velocity was very close to the general average; up to 18 seconds the azimuth steering was exceptionally good with a deflection of only 11 feet (west), beyond that time there was east movement but this was probably caused by fairly high winds. Motor pressure started down at 36.6 seconds and reached zero at 37.8 seconds.

Data

Trajectory data indicated the following:

a. Missile velocity was very close to the general average during powered flight.

b. Azimuth steering was exceptionally good up to 18 seconds. From 18 to 28 seconds east movement rose to about 37 fps. This movement remained fairly constant to the end of burning.

c. Pitch program was near normal at 18 seconds but did not show a normal increase thereafter.

Telemetry data indicated the following:

d. Motor pressure started down at 36 seconds and reached zero at 37.8 seconds.

e. The turbine started to overspeed at 36.6 seconds, reaching a maximum at 37.3 seconds. This maximum was approximately 130 percent of the average during normal operation. After remaining at the peak for about 0.2 second, the turbine speed dropped off rapidly to zero.

f. The steering system may or may not have been cut off at the time the turbine speed started down. The evidence is not conclusive.

Remarks

An important fact was that the combustion pressure started down before the turbine speed started to increase. This immediately limits the fault to one which would unload the turbine. Among such possibilities are: (1) large rupture in the alcohol as oxygen piping, (2) closure of the main alcohol valve, (3) closure of the main oxygen valve and (4) closure of the preliminary alcohol valve.

It seems highly probable that a large rupture in the alcohol system would result in a fire or an explosion that would be visible to the telescopes. A large rupture in the oxygen system probably would produce visible evidence.

Tests have demonstrated that the main valves can not be closed fully against pump pressure. When air is applied to close either or both of these valves, the combustion pressure should not drop over 50 percent and the turbine speed should not change over five percent. Since the combustion pressure went to zero and the turbine speed increased by about 30 percent, it seems clear that the main valves did not produce the shut-down.

Closure of the alcohol preliminary valve will produce a complete loss of combustion pressure in a short time. The evidence therefore points to this valve as the cause of the trouble. In addition,it should be noted that this valve is more susceptible to accidental closure than are the main valves since both electrical power and air are required to keep it open. A break in either the electrical system or the air system will cause it to close.

. The presumption is that the failure was caused by vibration. Under this assumption, a break in the electrical wiring is more probable than a break in an air line. The electrical circuit included one relay contact (a6x), one connector (k) and a number of junction points. Any one of these could be the location of the break. There appears to be no data to allow a closer determination of the probable source of the trouble.

Probable Cause

A break in the control wiring to the alcohol preliminary valve causing this valve to close, thus cutting off alcohol to the motor.

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